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Office of Aviation Research
Washington, D.C. 20591

TP 12642

Transport Canada Aviation
330 Sparks St.
Ottawa Ontario Canada

JAA Headquarters
2130 KA Hoofddorp
Netherlands

International Conference On Cabin Safety Research

Harrah's Casino-Hotel
Atlantic City, N.J.
November 14-16, 1995

Conference Proceedings

March 1996

Final Report

U.S. Department of Transportation
Federal Aviation Administration

Transport Canada
Aviation

Transports Canada
Aviation

Joint
Aviation
Authorities

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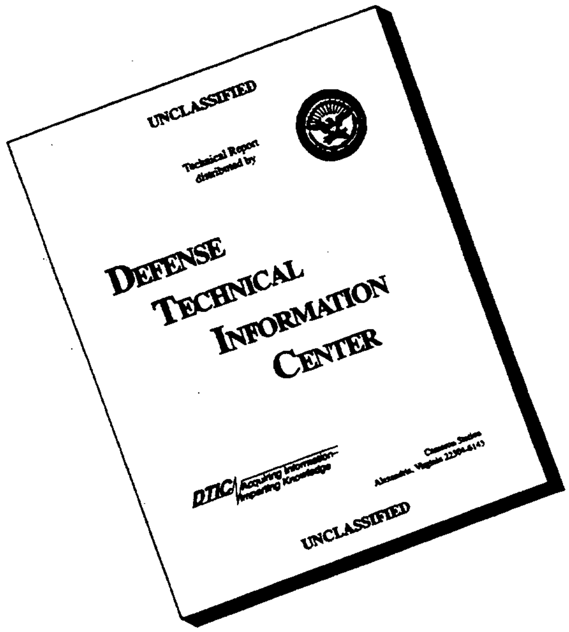

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FAA Technical Monitor, Richard Hill

16. Abstract
This publication contains the proceedings of the International Conference on Cabin Safety Research held in Atlantic City, New Jersey, November 14-16, 1995. Presentations were made and break out sessions were held in the following areas: evacuation, in-flight emergencies, crash dynamics and fire safety.

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EXECUTIVE SUMMARY

The International Conference on Cabin Safety Research was conceived as a vehicle to present to the aviation community a proposed Federal Aviation Administration (FAA), Transport Canada Aviation (TCA), Joint Aviation Authorities (JAA) Cabin Safety Research Program and obtain feedback on same. The detailed plan for the program as well summaries of present and planned FAA, TCA and JAA cabin safety research activities can be found in the report "Proposed Cabin Safety Research Program (Transport Category Airplanes)," FAA number DOT/FAA/AR-95/14, TCA number 12570.

The conference included an overview and outline of the proposed program as well as presentations and discussions in the areas of evacuation, crash dynamics, inflight emergencies, and fire safety. Breakout sessions provided attendee participation and input.

The Cabin Safety Research Program is dynamic, and will be refined as required. This event provided an excellent technology exchange forum and a solid foundation for planning future cabin safety research.

Comments, input and priorities expressed at the conference and in these proceedings represent those attendees at the conference. These will be considered for improving the cabin safety program along with continually sought input from the public and aviation community.

These proceedings were compiled by Galaxy Scientific Corporation of Egg Harbor Township, New Jersey.

OPENING SESSION

Tuesday, November 14, 1995

Federal Aviation Administration

International Conference on
Cabin Safety Research

Ava L. Robinson

Special Assistant to the Director
Aircraft Certification Service

Federal Aviation Administration
Objectives of the Conference

Two Main Objectives

- Present the Cabin Safety Research Program Plan to the Public
- Get Input from the Public on the Direction that Future Research Should Take

Federal Aviation Administration
Objectives of the Conference

First Objective is to Present the Cabin Safety Research Program Plan to the Public

- The Plan is the First Attempt to Integrate All Cabin Safety Research
- The Plan Also Proposes to Use Methodologies Not Previously Used
- The Plan Provides a Means to Take Account of International Cooperation

Federal Aviation Administration
Objectives of the Conference

Second Objective is to Get Input from the Public on the Direction that Future Research Should Take

- Inputs Solicited on Various Cabin Safety Subjects to Reflect Different Segments of the Aviation Industry
- Separate Breakout Sessions to Discuss Concerns of Any Attendee

Federal Aviation Administration
Objectives of the Conference

Another Objective is to Provide a Frame of Reference to the Public on Who Within the FAA is Responsible for Research Programs

- Understand the Responsibilities of the Various Organizations
- Put Names and Faces Into Context

Transport Canada Transports Canada

Cabin Safety
Research Program
(Transport Category Airplanes)

FAA JAA TCA

- - -

OVERVIEW

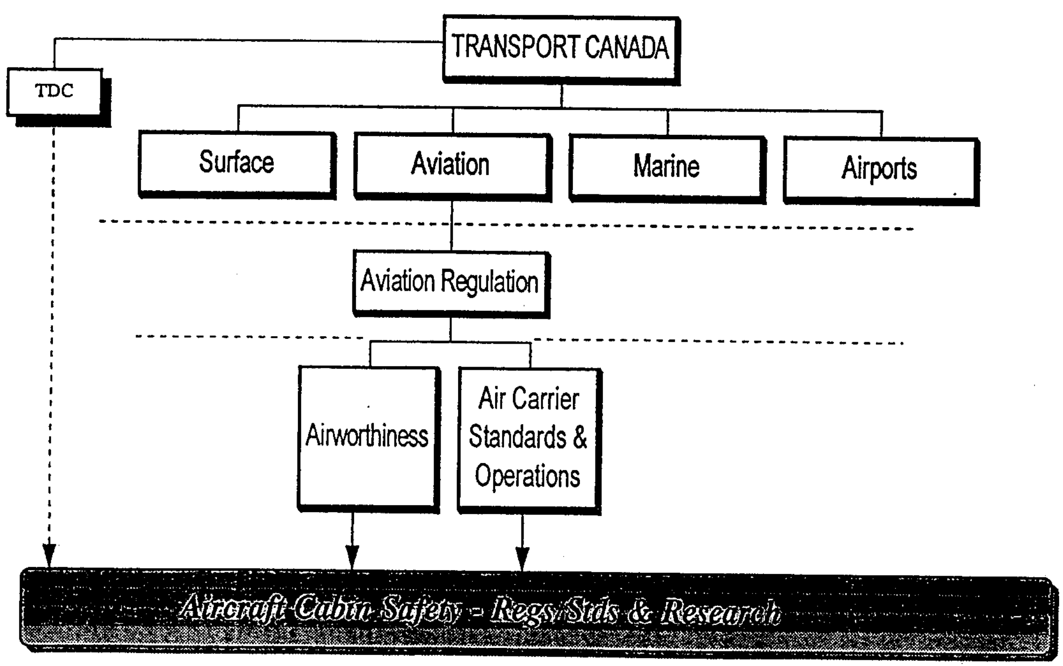
Present . . .

- Brief summary of
  TCA Organization
  Responsibilities / Research

- Overview of
  FAA / JAA / TCA
  Cabin Safety Research Program

Transport Canada Aviation (TCA):

- One of 4 Groups within Transport Canada
- Includes, amongst others, the Airworthiness Branch and the Air Carrier Standards & Operations Branch, which are responsible for cabin safety regulations/standards and research within the Aviation Regulation Directorate
- Research performed either directly by Branches/Directorate, or through the Transportation Development Centre (TDC), (the R&D 'arm' of Transport Canada)



Program - Background . . .

- In the past, cabin safety research programs were generally done independently of one another

- Recently, North American and European authorities have collaborated on a number of research programs, such as:
  - Passenger Protective Breathing Equipment (PPBE)
  - Cabin Water Spray (CWS)
  - Effect of Cabin Crew Behaviour on Emergency Evacuation

Program - Background

- These very successful programs have demonstrated the benefit of a coordinated approach to research

- International nature of aviation, commitments to harmonization and budgetary constraints further dictate cooperation in research

The Objective of the Program is to . . .

- Enhance the effectiveness & timeliness of cabin safety research to achieve improved and more consistent rules/standards

by establishing a framework for the . . .

- systematic joint identification, prioritization & coordination of needed work
- facilitation of cooperative, joint and complementary programs

The Plan

- Defines extent & scope of cabin safety
- Establishes 'mechanisms/tools' to identify research needs and establish priorities
  - Benefit/Risk Analysis
  - Database
- Sets-up the terms of the Program's management
  - Steering Committee
  - Technical Group
- Provides specifics of on-going and planned research

In the context of the Program,

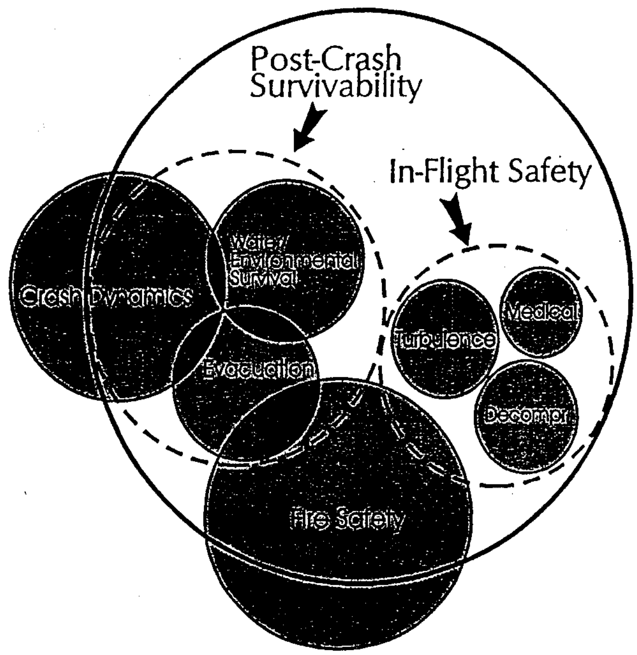
- Cabin safety means . . .

  " - Protection against acute events
  which can be addressed by changes
  within (or closely associated with) the cabin - "

The Program addresses two aspects of Cabin Safety:

- Post-Crash Survivability
  - – Physical protection from the crash
  - – Egress (evacuation / fire protection)
  - – Water/environmental survival
- In-Flight Safety
  - – Turbulence
  - – Decompression
  - – Fire protection
  - – Medical considerations

Cabin Safety



. . . OVERVIEW

In summary . . .

- The Authorities have developed the Program to enhance the effectiveness and timeliness of cabin safety research

- The Program will achieve this by providing a systematic approach which
  - Allows effective joint identification, prioritization and coordination of research activities
  - Facilitates the establishment of cooperative, joint and complementary research programs

. . . OVERVIEW

Industry deserves and has a vested interest in having 'good' & consistent standards and regulations,

i.e. standards which set meaningful safety goals that can be realistically achieved

The Cabin Safety Research Program will provide the authorities with a tool necessary to achieve this!

. . . OVERVIEW

FAA, JAA and TCA
are committed to
the Program's objectives

FAA

Cabin Safety

Regulation

and

Research

FEDERAL AVIATION ADMINISTRATION

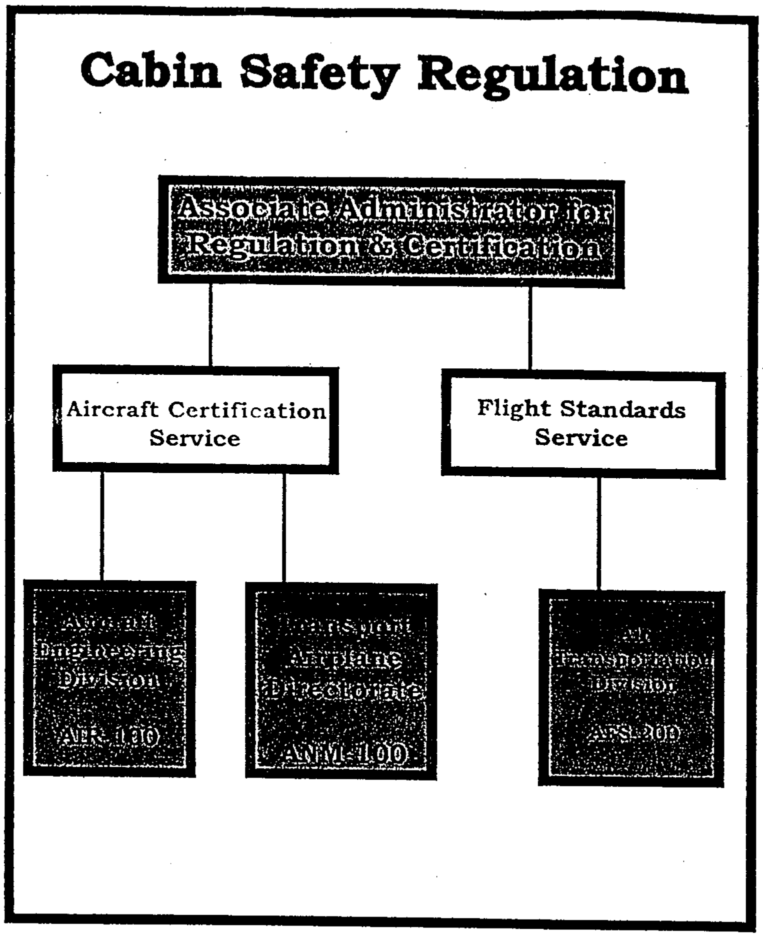
Cabin Safety Research Program

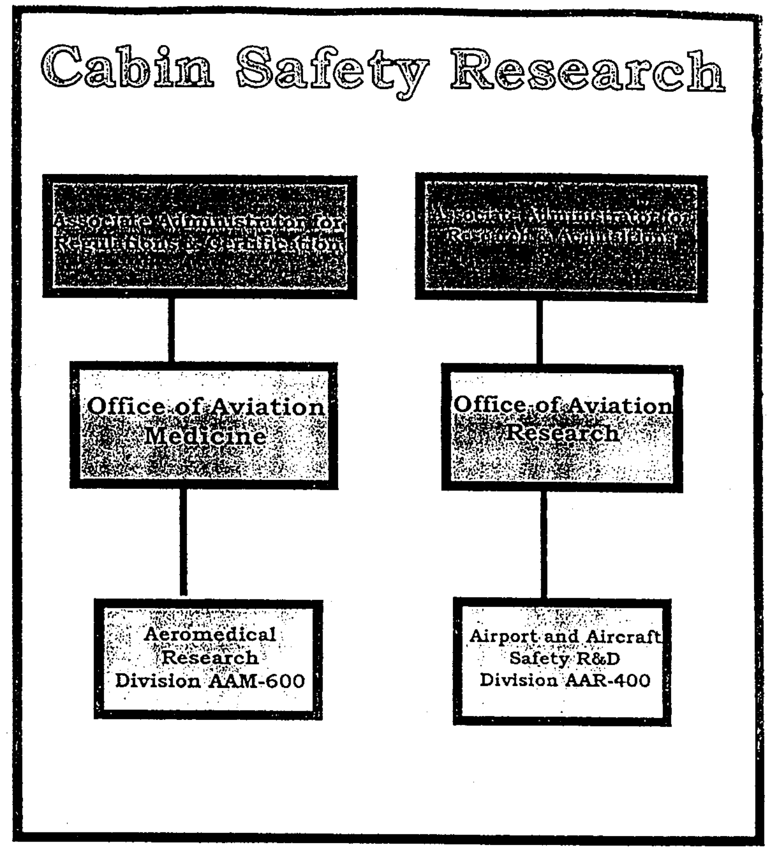
Organization and Function
of Management and Technical Groups

FAA

JAA

TCA


Cabin Safety Regulation
Associate Administrator for Regulation & Certification
Aircraft Certification Service
Flight Standards Service
Division
Transport Airplane Directorate
ANM-100
Division


Cabin Safety Research
Office of Aviation Medicine
Office of Aviation Research
Aeromedical Research Division AAM-600
Airport and Aircraft Safety R&D Division AAR-400

Cabin Safety Research Program

Organization

Cabin Safety Research Program
Program Management

Agreement Among:

FAA
CAA
TCA
Others?

Cabin Safety Research Program
Program Management

Two Levels of Management:

- **Steering Committee**
- **Technical Group**

Cabin Safety Research Program
Program Management

Steering Committee:

- Senior management representative(s) from each participating organization.

Cabin Safety Research Program
Program Management

Steering Committee:

Provides:

- General direction
- Guidance

Establishes:

- Broad priorities

Cabin Safety Research Program
Program Management

Technical Group:

- Representation from both Research and Regulation from each organization.
- Core group (1 to 3 from each organization)
- Bring in Technical Experts as needed.

Cabin Safety Research Program
Program Management

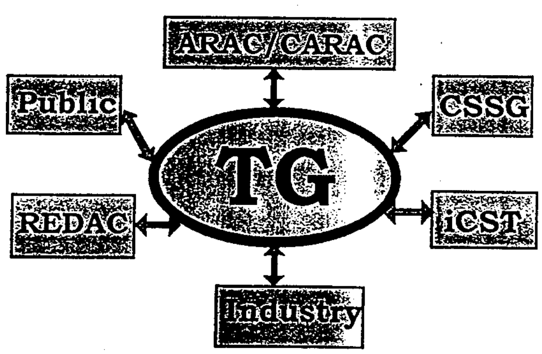
Technical Group:

Tasked to:

- Identify research of mutual interest
- Share/define access to results
- Define jointly funded research programs
- Define & coordinate cooperative research

Cabin Safety Research Program
Program Management

Interface and consult with relevant parties



Joint Aviation Authorities
Research & Development

Presented by:

Vittorio Fiorini, JAA (*RAI*)

Novembre 14, 1995

JAA R & D

International Conference on Cabin Safety Research
ATLANTIC CITY, N.J. USA 14-16 November 1995

JOINT AVIATION AUTHORITIES
RESEARCH COMMITTEE

JAARC HAS REPRESENTATIVES FROM SEVEN JAA MEMBER STATES AND EUROPEAN UNION "TRANSPORT DIRECTORATE"

FRANCE

GERMANY

ITALY

NETHERLANDS

SPAIN

SWEDEN

UNITED KINGDOM

JOINT AVIATION AUTHORITIES
RESEARCH COMMITTEE

PRIMARY TASKS OF JAARC

TO DEFINE SPECIFIC RESEARCH TO SUPPORT JAA REGULATIONS

(COVERING DESIGN, MANUFACTURE OPERATION, MAINTENANCE, LICENCING AND ENVIRONMENT)

TO MINIMISE UNNECESSARY DUPLICATION OF RESEARCH

TO ENCOURAGE COOPERATION ON RESEARCH

TO LIAISE WITH EUROPEAN UNION AS REQUIRED

TO SHARE THE RESULTS OF RESEARCH

JOINT AVIATION AUTHORITIES
RESEARCH COMMITTEE

ACHIEVEMENTS OF THE JAARC IN 1994/1995

1) JAA MEMBER STATES RESEARCH SUMMARY DOCUMENT PRODUCED IN JANUARY 1994 COVERING SAFETY AND ENVIRONMENTAL RESEARCH IN FIVE JAA STATES - FRANCE, GERMANY, ITALY, NETHERLANDS & UK.

2) JAA RESEARCH POLICY PAPER APPROVED BY JAA COMMITTEE IN 1994, THIS PAPER PROPOSED THAT THE JAA RESEARCH COMMITEE SHOULD CONCENTRATE ON DEFINING ELEVEN "PILOT PROJECTS" DURING 1994/95

3) A STATEMENT OF INTENT RELATING TO COOPERATION BETWEEN FAA AND JAA ON AVIATION SAFETY AND ENVIRONMENTAL RESEARCH SIGNED ON JUNE 9, 1995
FAR/JAR HARMONIZATION PROCESS
CALLS FOR RESEARCH ACTIVITIES HARMONIZATION

JOINT AVIATION AUTHORITIES
RESEARCH COMMITTEE

"PILOT PROJECTS"
(ALL THESE PROJECTS ARE CURRENT JAA REGULATORY ISSUES)

HUMAN FACTORS
OCCUPANT SURVIVABILITY
SIDE-FACING SEATS
CABIN EVACUATIONS
ICING HAZARD
DAMAGE TOLERANCE
HALON REPLACEMENTS
GNSS (AIRBORNE EQUIPMENT APPROVAL)
WET & CONTAMINATED RUNWAYS
NOISE & EMISSIONS
ARTIFICIAL BIRDS
LIGHTNING
GROUND COLLISION AVOIDANCE SYSTEM (GCAS)
EXPLOSIONS (ON BOARD)

JOINT AVIATION AUTHORITIES
JAA RESEARCH COMMITTEE

"POLICY PAPER ISSUES"

FUNDING

PILOT PROJECT WILL BE FUNDED NATIONALLY AND BY MAKING USE OF EUROPEAN UNION FUNDING AVAILABLE TO PARTNERSHIPS AMONG JAA STATES INDUSTRIES, UNIVERSITIES AND RESEARCH CENTERS

RESEARCH TASKS DEFINITION

JAARC HAS WORKED VERY CLOSELY WITH EUROPEAN UNION "TRANSPORT DIRECTORATE" TO DEFINE RESEARCH PROJECTS TO IMPROVE SAFETY AND ENVIRONMENT WITHOUT UNNECESSARY DUPLICATION
CONTACTS ARE IN PLACE ALSO WITH "SCIENCE AND TECHNOLOGY DIRECTORATE" AND "TELEMATICS DIRECTORATE"

PROJECT ADVISORY GROUPS

FOR COMPLEX SUBJECT (E.G. HUMAN FACTORS CABIN SAFETY AND OTHERS) A GROUP OF EXPERTS WILL ASSIST JAARC IN DEFINING AND COORDINATING RESEARCH PROJECTS

INDUSTRY INVOLVEMENT

A PERIODIC ANNUAL CONSULTATION WITH INDUSTRY TAKES PLACE TO EXAMINEJAA RESEARCH COMMITTEE PROPOSALS AND PRIORITIES

EUROPEAN UNION "TRANSPORT DIRECTORATE" RESEARCH STUDY ON AIRCRAFT PASSENGER SURVIVABILITY

AIR TRAFFIC INCREASE FORECAST (DOUBLE BY THE NEXT 10/15 YEARS) WILL RENDER THE PRESENT ACCIDENT RATE (NEARLY CONSTANT DURING THE PAST 10 YEARS) NO LONGER ACCEPTABLE.

TODAY MANY OF AIRCRAFT ACCIDENTS ARE SURVIVABLE TO A VARYING EXTENT.

THE PROPORTION OF SURVIVABLE ACCIDENTS SHALL INCREASE BY IMPROVING AIRCRAFT PASSENGER'S CHANCES OF SURVIVING AIRCRAFT CRASH AND/OR FIRE.

OTHER RESEARCH TASKS

EUROPEAN UNION "TRANSPORT DIRECTORATE"

4th FRAMEWORK PROGRAM (1996-1998)

4.2.1/26 ENHANCED PASSENGER CRASH PROTECTION THROUGH IMPROVED INTEGRITY of seat attachment, seat design, passenger restraint systems, stowage bin and galley integrity for a range of typical aircraft crash loading conditions.

4.2.1/27 TO DEVELOP ASSESSMENT TECHNIQUES FOR IMPROVED "PASSENGER FRIENDLY" CABIN INTERIORS based on existing Head Impact Criteria (HIC) and automotive industry standards.

4.2.1/28 DEFINITION OF SPECIFIC PERFORMANCE REQUIREMENTS TO EXTINGUISH FIRES IN THE VARIOUS PARTS OF THE AIRCRAFT USING "ON-BOARD" (HALON REPLACEMENTS) and "external" systems.

4.2.1/29 TO DETERMINE THE CRITICAL ELEMENTS FOR RAPID PASSENGER EVACUATION to improve evacuation provisions for existing and future aircraft designs and to develop a passenger evacuation model to assess the influence of different passenger seating and cabin interior configuration on evacuation.

ECC - AIRS

A EUROPEAN COORDINATION CENTER FOR AIRCRAFT INCIDENT REPORTING SYSTEM IS UNDER DEVELOPMENT. A pilot system is ready at JRC of ISPRA (Italy) for the European Union and will store the incident information according to ICAO format submitted by JAA States.

MAIN HEADLINES OF THE FAA/JAA/TCA JOINT CABIN SAFETY RESEARCH PROGRAM

1) PAST ACCIDENTS ANALYSIS CAN GIVE A GOOD GUIDE TO THE FUTURE ACTIVITIES.
RISK BENEFIT ANALYSIS OF PAST ACCIDENT DATA BASE IS A PREREQUISITE TO ASSIGN PRIORITIES TO RESEARCH PROGRAMS.
A REASONABLE CLEAR PERSPECTIVE OF POSSIBLE SAFETY BENEFITS IS NEEDED TO JUSTIFY RESEARCH FUNDING.

2) THE UNDERSTANDING OF PARAMETERS THAT AFFECT SURVIVABILITY.
WHICH FACTOR AND COMBINATION OF FACTORS INFLUENCE THE LEVEL OF SURVIVABILITY, STATISTICAL ANALYSIS TO DETERMINE PROBABILITIES USED.

3) ASSESS THE IMPACT OF CHANGING PARAMETERS AND MODELLING TOOLS IN ORDER TO IDENTIFY RESEARCH NEEDS IN THE PRENORMATIVE DOMAIN.

Risk Analysis: Passenger Airplane Accidents[1]

Richard Lee Smith and Paul E. Lehner
Systems Engineering
George Mason University
Fairfax, VA 22030-4444

Abstract

It is becoming increasingly important to have a compelling justification for regulations and research programs. This paper briefly examines some alternative methods for aviation safety analysis and suggests that all of these methods require a healthy dose of subjective expert judgment to extrapolate from analysis results to real-world risk assessment. As a consequence, methods for aviation safety and risk analysis that explicitly incorporate expert judgment are proposed.

Introduction

In recent years, it has become increasingly important to formulate strong justifications for regulations and research programs related to the specification of regulations. Regulators often find that a persuasive analysis is needed before a regulation or related research program is accepted. The domain of passenger aircraft safety is no exception to this trend.

In this paper we examine the problem of developing a method for the predicting future passenger airplane accident[2] rates and the number of persons killed in these accidents[3]. We briefly examine some alternative methods, and based on this examination recommend a general approach that we believe is appropriate for contributing toward specification of reasonable and justifiable cabin safety regulations. Our work in this area is an early step in research to develop the methodology for the fire risk analysis and management for passenger airplanes.

---

[1]Research funded by a research grant (FAA Grant Number 94-G-041) from the Federal Aviation Administration.

[2]For this analysis we will use the following definitions for accidents and incident:

"An aircraft *accident* is an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage. *Incident* means an occurrence other than an accident, associated with the operation of an aircraft, that affects or could affect the safety of operations. 49CFR 830.2."

[3]We will not deal with planes destroyed or deaths due to acts of war, suicide, or sabotage.

Some Alternative Methods for Estimating Risks and Safety Benefits.

Detailed Simulation Models.

Passenger aircraft transportation is a very large and complex system. It involves the air traffic controllers, the airport ground crews, and the passenger planes and their crews. It includes computers, machinery and people. Flying is not a simple thing for people to do. A detailed simulation model of such a system would include a very large number of variables, where (a) all of the variable values are virtually always consistent with a safe flight, yet (b) any of these variables could, in rare and unusual circumstances, contribute to an unsafe flight. In general, detailed models of this type are not good models for predicting risk probabilities. This is because for such models to make reliably valid probability predictions, the variable values must be specified accurately (or even worse, probability distributions over the variable values must be specified). In other words, detailed models with numerous variables contain numerous potential sources of error. Such models are often useful for analyzing very specific scenarios (where all the variable have assumed values), but are of little use in aggregating over possible scenarios to generate overall risk assessments. Using such models for risk assessment requires a substantial level of expert judgment to extrapolate from simulation results to real world application.

Statistical Analysis

An inspection of historical data (see Figure 1[4]) shows a significant decline in the fatality rate over the last 50 years, where data from recent years (e.g., see Figure 2[5]) suggests that the fatality rate fluctuates between 0 and 3 fatalities per hundred thousand departures. Unfortunately, the year to year fluctuation is sufficient that it would be difficult to discern the extent to which various elements of the system (e.g., different types of aircraft) make a significant contribution to overall safety. (How many departures of 757s).

Unfortunately, statistical analyses are limited to analysis of historical data, and it is often unclear as to the extent to which historical data applies to projecting future trends in a somewhat different environment. For example, to what extent can one use historical data to predict the risks associated with flying the so-called megaplanes (with two levels of passenger compartments). While statistical analyses can certainly be used to estimate rates and extract historical trends, it still takes a substantial level of expert judgment to extrapolate the implication of statistical analyses to projecting future risks.

Accident Case Analysis

In accident case analysis one takes a subset of historical accidents, examines each in detail, and

---

[4]Data from *ATA Airline Safety Record 1938-94*, Air Transport Association of America.

[5]Data from an NTSB press release of Jan. 19, 1995 and data from other sources for 1995.

Figure 1.

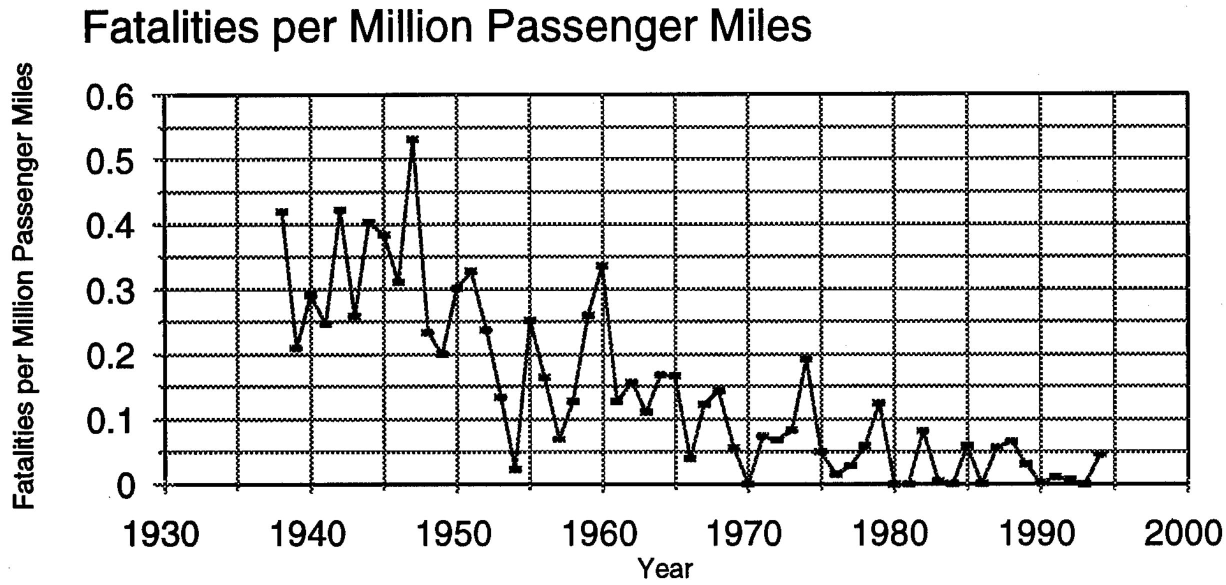
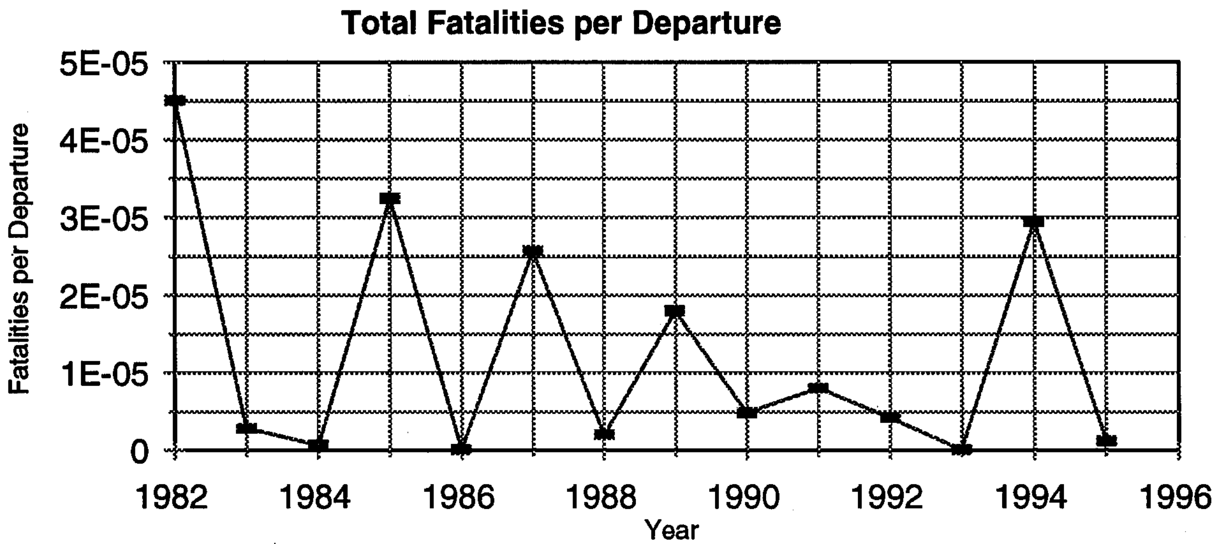


Figure 2.



hypothesizes the number of lives that would have been saved or lost if a proposed cabin safety feature where in the airplane, and directly extrapolates from this analysis the number of lives saved that would be saved in the future. This type of analysis has been used by the FAA [Hill et al 1992] and others [Cherry 1995]. Unfortunately, as typically employed this type of analysis fails to consider that aviation

authorities almost invariably make changes to aircraft of operational procedures to guarantee that known causes of previous accidents will not reoccur. History is not likely to repeat itself.

More formally, one can describe the difficulty probabilistically. Let A be the proposition that there is a particular scenario that causes an airplane accident with a fire and let F be the number of fire deaths due to this accident. Basic probability theory allows us to write

$$P(A,F|X) = P(F|A,X)P(A|X). \qquad (1)$$

Thus we see that the probability of A (the particular accident scenario) and F (number of fire deaths) together given X, is equal to the probability of F given A and X multiplied by the probability of the accident scenario occurring in the circumstance X.

Accident analysis is aimed at understanding the parts of X that contributed the most to the probability of the accident scenario and changing them so the probability of this accident scenario is reduced. Whenever an action is taken to create such a new set of circumstances, W, which replaces X and which results in greatly reducing the probability of A. That is

$$P(A|W) << P(A|X). \qquad (2)$$

The new probability of A and F is now given by

$$P(AF|W) = P(F|AW)P(A|W). \qquad (3)$$

The changes introduced in going from X to W will normally have little impact on the probability of fire deaths assuming an accident and circumstances X or W [$P(F|AW) = P(F|AX)$], therefore we would expect

$$P(AF|W) << P(AF|X). \qquad (4)$$

Thus whenever an action is taken to reduce the probability of the occurrence a particular accident scenario that involves fire deaths, the probability of fire deaths is also reduced. We see that to determine the lives saved by the fire safety intervention it is not sufficient to evaluate the impact of the fire safety feature alone. One must also include the nonfire safety improvement. This complicates the analysis problem substantially, since it in effect requires estimation of a probability distribution over possible accident scenarios. Once again, extrapolating from analysis results to real world risk estimation is not straightforward, and requires substantial expert judgment.

Bayesian Decision Theory

All of the above methods are characterized by the fact that they require substantial expert judgment to extrapolate from analysis results to real world risk estimation. As such, they should be viewed as methods for producing informational inputs to expert risk judgments; and not as alternatives to human expert judgment. Indeed, the problem of aviation risk analysis is sufficiently complex and sophisticated

that it seems unlikely that a completely formal and objective method will ever be developed. Expert subjective judgment will inevitably be the basis of aviation risk estimation.

Given the inevitability of subjective expert judgment in aviation risk analysis, it would seem that a method for effectively using and aggregating such judgments is needed. The discipline of Decision Analysis [Howard 1990] provides a collection of such methods. Decision analysis is based on Bayesian decision theory (BDT) which is a normative theory of coherent inference and decision making [Cox 1961; Tribus 1969].

Of the various decision analytic methods, the most appropriate for aviation risk analysis seems to that of *influence diagrams*. An influence diagram is a graphical and computational model of a decision problem. The graphical nature of influence diagrams facilitate communication between various parties involved in an inference or decision problem that makes explicit the inter- and independencies among variables [Howard 1990]. Computationally, influence diagrams are equivalent to well-formed fault or event trees, but they grow more slowly than trees as the number of variables increases [Holtzman 1989].

Graphically, influence diagrams are composed of the following.

Decision nodes which are normally portrayed as square or rectangle shaped nodes.
Value nodes which are normally portrayed as a hexagon or octagon.
Chance nodes which are normally portrayed as circles, ellipses, or rounded corner nodes.
Arcs which are normally portrayed as arrows.

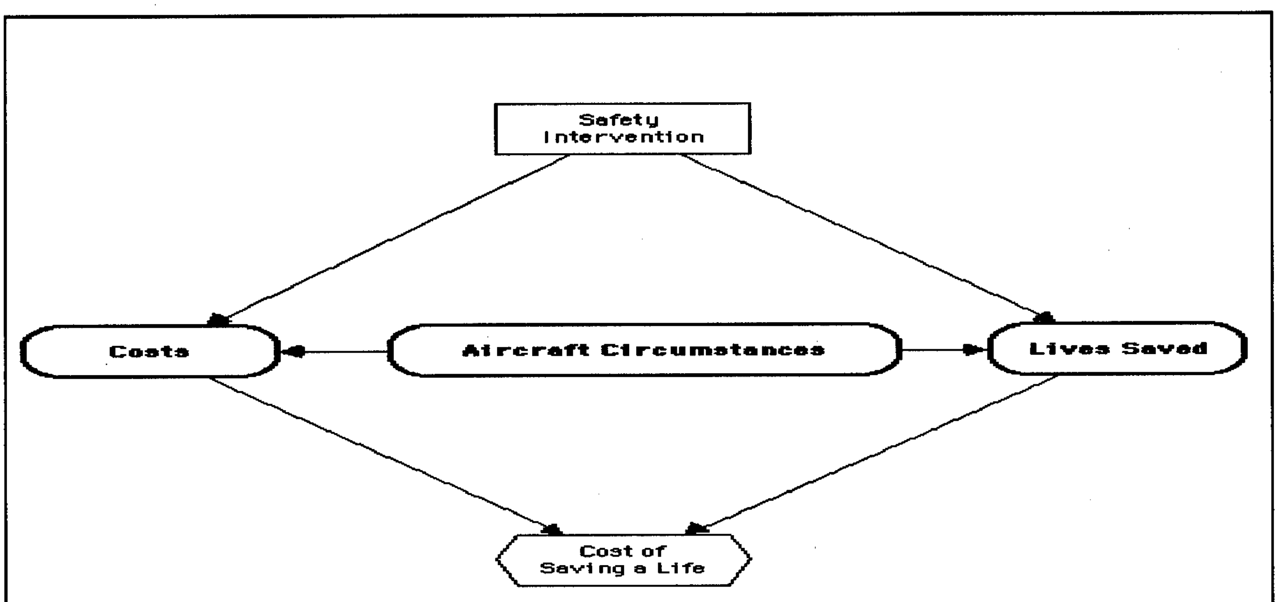


Figure 3. Top-level Influence Diagram

The top level of an influence diagram should be understandable by almost anyone. Referring to Figure 3

which is the top-level of an influence diagram for safety analysis for cabin safety, we see at the top of the figure the decision node. At the bottom of the figure we see the value node. It is the role of the decision maker to determine what decisions are to be considered and what to use to evaluate the relative merit of the possible consequences of the various possible decisions. If we ignore the node in the middle of Figure 3. we have two additional nodes, costs & lives saved. The diagram indicates that the variable "Safety Intervention" influences the value of the variables "Costs" and "Lives Saved." Also the variable "Aircraft Circumstances" is relevant to determining the values of "Costs" and "Lives Saved." Finally, "Costs" and "Lives Saved" are relevant to determining the values of "Cost of Saving a Life."

If one knows the values for these four nodes above the "Cost of Saving a Life" node and the relationships between the values of the various nodes, then the value of the "Cost of Saving a Life" node can be determined and the analysis is complete.

While it is very desirable to have the simplest model possible, the above is too simple to satisfy our requirements. The main objection to this model is that it does not allow us to evaluate the impact of some safety schemes. To achieve this capability, we interpret the "Lives Saved" node as an influence diagram submodel which is shown in Figure 4. The small arrowhead to the left of the "Net Lives Saved" node indicates there is at least one node not shown in this diagram that has input to the

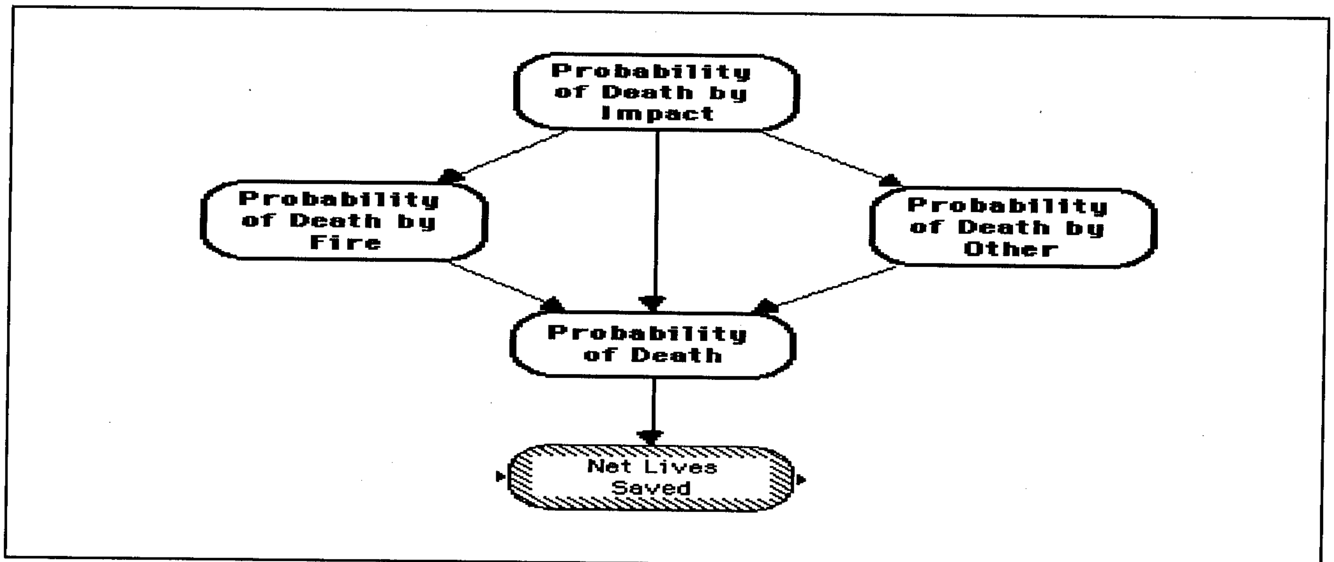


Figure 4. Lives Saved Submodel

determination of the value of this node. Again there is not sufficient detail to model the impact of a safety intervention, so we expand the node "Probability of Death by Fire" into the influence diagram shown in figure 5. This process of expanding nodes continues until we have the simplest model that will satisfy our modeling requirement.

In Figure 6 is shown an example of the documentation of a node in our influence diagram. The software used to create this influence diagram is Demos, a product of Lumina Decision Systems, Inc.

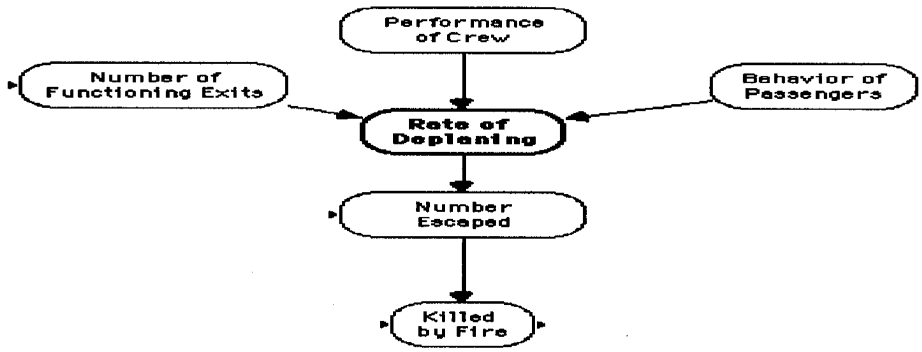


Figure 5. Submodel Probability of Fire Death

Chance	Fire_dead	Units:
Title:	Killed by Fire	
Description:	The number of persons in the airplane killed by fire.	
Definition:	exp Impact_sur * Num_escape	
Inputs:	Impact_sur Impact Survivors Num-esca... Number Escaped	
Outputs:	Number_kill Probability of Death	

Figure 6. Documentation of a Node

In the top left-hand corner is the type of node "Chance." Next to this is the computer name for the node, "Fire_dead." Then on the right of the top line one can enter any units associated with this variable. On the next line is the title which appears in the graphical representation of the node. At the beginning of the next line is the heading "Description." After this heading there is a brief description of this node. However, the description can be as long as one wishes. This is where one can enter the full description of the node including any sources, arguments, explanations, etc. This would include, for instance, results of simulation, statistical and case analyses that were used as a basis for the probability

judgments that are encoded in the node. The "Definition" shows the relationship between the "Inputs" variables and this node. Finally, the "Outputs" shows what nodes use the value of this node as input.

Once developed an influence diagram can be used to either calculate the expected utility of various cabin safety options or to calculate the expected utility of information that could result form alternative research programs, (i.e., the expected increase in expected utility that would result from the knowledge gained from a proposed research program.).

Conclusion

In summary, we argue that the decision analysis provides an appropriate approach for performing risk assessment in aviation safety. It is uniquely appropriate in that it incorporates and integrates subjective expert judgment (which is inevitably required) with other sources analytic input (viz. simulation, statistical and case analyses). As a result, we believe that aviation safety analysis methods should be developed that are based on Bayesian decision theory. Our research is oriented toward developing methods and decision analytic models that are specific to aviation safety.

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Analysis of Factors Influencing the Survivability of Passengers in Aircraft Accidents

R.G.W. CHERRY & ASSOCIATES LIMITED

1 INTRODUCTION

A research study has been carried out on behalf of the Commission of the European Communities to analyse the factors which affect survivability of passengers in aircraft accidents and to assess their significance. A combination of a statistical approach together with an in-depth analysis has been used in order to determine the importance of factors influencing survivability. The study has necessitated the generation of a Survivable Accidents database. Software to access specific accidents or groups of accidents, and to carry out mathematical and statistical modelling has also been developed. This paper describes some of the work carried out to date in both the statistical analysis of Survivable Accidents and the analysis of factors influencing the survivability of occupants.

2 SELECTION OF ACCIDENTS AND ACCIDENT DATABASE

2.1 Survivable Accident Definition

In order to select accidents for study a non-subjective definition of a survivable accident was required.

There are several definitions of a Survivable Accident most of which are similar in concept to that contained in the "Aircraft Crash Survival Guide" published by the U.S. Army Research and Technology Laboratories:-

"An accident in which the forces transmitted to the occupant through his seat and restraint system do not exceed the limits of human tolerance to abrupt accelerations and in which the structure in the occupants' immediate environment remains substantially intact to the extent that a livable volume is provided for the occupants throughout the crash sequence."

However definitions of this kind have not been used in the selection of accidents in this research study for the following reasons:-

- For any particular accident, survivability potential may vary significantly dependent on occupant location.

- The definition is subjective and hence categorisation will vary dependent on the analyst's assessment of the environment to which the occupants were subjected.

- Whilst for a particular accident the hazardous environment to which occupants were subjected may have been non-survivable this does not infer that improvements to Survivability Factors would not have resulted in survivors.

For these reasons accidents have been categorised as Survivable on the basis of the following simplified, non-subjective definition:-

"An accident in which at least one occupant survived or there was potential for occupant survival."

Accidents resulting from acts of war, terrorism and sabotage have been excluded from this study.

2.2 Accident Database

A computer database has been generated containing 548 Survivable accidents to aircraft operating scheduled or non-scheduled passenger flights and of these 344 were fatal accidents. The U.K. CAA World Airline Accident Summary(ref. 1) has been used as the prime data source. Entries are contained for all 548 accidents contained on the database although information is not currently available for all fields on all accidents

The following accident details are contained in the database:-

Accident Circumstances

Accident Reference Number
Date
Aircraft
Aircraft Registration
Aircraft Operator
Location
Nature of Flight
Occupant and Occupant Injury Details

- Total Aboard
- Crew Fatalities
- Passenger Fatalities
- Total Fatalities
- Crew Serious Injuries
- Passenger Serious Injuries
- Total Serious Injuries
- Crew sustaining Minor or No Injuries
- Passengers sustaining Minor or No Injuries
- Total Occupants sustaining Minor or No injuries

Fatality Rate
Survivability Category
Accident Report Reference
Phase of Flight
- Parked
- Taxying
- Take-off
- Aborted Take-off
- Climb
- Flight
- Descent
- Approach
- Go-around
- Landing

Weather Conditions
- Visibility
- Precipitation
- Wind
- Other Weather Conditions

Runway Vicinity
- Within the vicinity of the airfield
- Outside the vicinity of the airfield

Day/Night

<u>Accident Details</u>

Fire
- Fire (extent unknown)
- Fire (total)
- Fire (in the cabin)
- Fire (other than in the cabin)
- Smoke
- No Fire or Smoke

Extent of Aircraft Damage
- Destroyed
- Substantial
- Minor
- None

Aircraft Orientation
- Normal (Aircraft Upright)
- Aircraft Upright but axes not horizontal (due to gear failure)
- Aircraft Upright but axes not horizontal (due to uneven terrain)
- Aircraft inverted or partially inverted

Aircraft partially or totally on its side

- Fuel Tanks Ruptured
  - Fuel Tanks ruptured
  - Fuel Tanks not ruptured
- Cabin Ruptured
  - Fuselage ruptured (by impact or fire)
  - Fuselage not ruptured
- Ditching
  - Ditching
  - Planned Ditching
  - Unplanned Ditching
  - Not Ditched
- Passenger Seat detachment
  - Seats detached
  - Seats not detached
- Landing gear Configuration
  - All up
  - All down
  - Abnormal
- Slide Deployment
  - Assist means were used
  - Assist means were not used
  - Assist means used with one or more failed
  - Number of Slides Deployed
  - Number of Slides Failed
- Exits
  - Exits were opened
  - Exits not opened
  - One or more exits failed to open
  - Number of Exits Opened
  - The number of exits used and attempted to be used.
  - Number of Exits Failed
  - The number of exits attempted to be used which did not open (sufficiently to allow egress)
- Overrun
  - Aircraft overran the runway
  - Aircraft did not overrun the runway
- Emergency Evacuation

3 STATISTICAL ANALYSIS OF SURVIVABLE ACCIDENTS

The generation of an Accident Database has allowed ready access to data to carry out statistical analysis of the circumstance and characteristics of survivable accidents, and to select specific accidents for in depth analysis.

3.1 Fatality Rate Distribution

The concept of a "fatality rate" has been used throughout this project. Fatality Rate is defined by the following expression:-

$$\frac{\text{Number of occupant fatalities}}{\text{Total number of occupants (passengers + crew)}}$$

If accidents resulted in a random fatality rate then it would be expected that the Probability Density Function (i.e. frequency of fatal accidents of a given fatality rate) would be as shown in Figure 1. That is if the proportion of fatalities (fatality rate) were random then the frequency of occurrence would be constant for all survivable accidents.

In reality, it is more likely that the fatality rate distribution will vary with some characteristic of the accident. From the work carried out to date it appears that fatality rate is not random. Figure 2 shows the Fatality Rate Probability Density Function for all fatal accidents on the data base - some 344 records. The distribution appears to exhibit a tri-modal distribution with relatively high frequencies of occurrence at low, mid-range, and high fatality rates.

Fatality Rate distributions have been derived from the database for survivable accidents with varying circumstance including the following:-

All during the period 1985- 1993
Fire related
Fuel tank rupture related
Fuselage rupture related
Ditching related
Overrun related

The distributions have also been analysed for aircraft of varying size and for both single and double aisle configurations. With the exception of Overruns no significant divergence from the tri-modal distribution exhibited in Figure 2, for all accidents on the database, could be determined for any of the accident circumstances or aircraft characteristics analysed. An explanation of the shape of the fatality rate distribution was sought since there seemed to be a consistent pattern for most Survivable Accidents. However when the fatality rate distribution is derived for accidents involving neither fire

nor ditching than the situation is markedly different as shown in Figure 3. The distribution results from 29 accidents and a closer study revealed that there are no accidents of this type on the database resulting in fatality rates in the range of .34 to .87.

Throughout this study cause of death has been categorised as follows:-

1) Impact
2) Mechanical Asphyxiation
3) Death as a result of fire
4) Asphyxiation
5) Drowning
6) Other (e.g. Cardiac Arrest, Loss in Flight)

The fatalities depicted in Figure 3. are attributable to Impact Trauma and Mechanical Asphyxiation, or are in the "Other" Category referenced above. For all three of these causes of death time is not a factor in survival, whereas fire and drowning related fatalities are influenced by the time available to escape the threat.

Whilst further work is required to verify any conclusions it would appear that:-

- accidents which do not involve fire or ditching tend to result in fatality rates at the extremes of the range.

- where survival is influenced by the time available to escape the threat, then the number of fatalities tends to be toward the middle of the fatality rate band.

3.2 <u>Fatality Rate Variation with Calendar Time</u>

The accident database developed for this project allows accurate evaluation of trends in survivability with calendar time. Software has been developed to provide menu driven access to the database to calculate a five year moving average of fatality rates for any selected set of accidents.

Figure 4 shows the five year moving average fatality rate for all fatal accidents on the database. It shows a relatively low level fatality rate during the early to mid 1980's which increases toward the end of the decade. It is thought not to be a random fluctuation since there is a large population of accidents in the analysis. It was considered that it might reflect variations in the reporting of fatal accidents rather than a real change in the trend of survivability. In order to assess whether standard of reporting was a significant factor a similar analysis was carried out for accidents occurring only in the United States of America or the United Kingdom. It was considered likely that the

majority of fatal accidents occurring in these countries are likely to be recorded in the U.K. CAA World Airline Accident Summary - the prime data source used for generating the database.

However the reduction in Fatality Rate experienced in the early to mid '80s followed by an increase at the end of the decade was still apparent, and hence it is unlikely that standard of reporting is a significant factor in the shape of the curve.

An investigation into this variation in fatality rate with calendar time for accidents of varying circumstance (e.g. Fire related, Ditching related) revealed a similar reduction during the early to mid 1980's

However the prime exception was for accidents involving causes of death which were solely impact related.

Figure 5 shows the fatality rate variation for those fatal accidents involving neither fire nor ditching (i.e. where the causes of death were solely impact related).

The characteristics of this curve are remarkably dissimilar to the norm in two respects:-

1) the fatality rate is significantly lower

2) the absolute change in fatality rate with calendar time is small.

It is interesting to note that accidents that did not involve fires or ditchings seem to show different characteristics to the other datasets investigated. This should be compared with the analysis work carried out on fatality rate distributions, which also showed that the accidents that did not involve fires or ditchings exhibited differing characteristics from the norm.

The effects of passenger load factor have not been investigated within the scope of this project but may have an influence on fatality rate reduction during the mid to late 1980's.

4 IN-DEPTH ANALYSIS OF SURVIVABLE ACCIDENTS

4.1 Method

4.1.1 Selection of Accidents

The in-depth analysis was carried out on 39 accidents. An attempt was made to select accidents such that they formed a representative sample of all survivable accidents on the database. The following criteria were used to make this assessment:-

i) the proportion of accidents by circumstance (e.g. cabin fire related, ditching etc.)

ii) the fatality rate distribution

iii) the average fatality rate

The comparisons are as follows:-

i) From an analysis of the accident database it is assessed that survivable accidents may be sub-divided as follows:-

42% fire related (cabin/total)
12% ditching related (planned or unplanned)
46% solely impact related

For the 39 accidents analysed the divisions by type are:-

46% fire related
18% ditching related
36% solely impact related

ii) The fatality rate, for the 39 accidents, exhibits a similar tri-modal distribution to that for all accidents on the database.

iii) The average fatality rate of the accidents analysed was approximately .3 compared with a fatality rate of between .3 and .4 experienced over the past decade for the accidents on the database.

It is considered that the accidents analysed represent a reasonably representative sample of all survivable accidents even though there are more ditching related, and less solely impacted related, accidents than an ideal sample would contain.

4.1.2 Avoidable and Unavoidable Fatalities

Whilst carrying out this analysis of accidents it was apparent that a significant proportion of fatalities were unavoidable in the sense that no survivability factors could be identified which would have prevented their occurrence. These unavoidable fatalities are considered important in the analysis since they represent the "floor" at which no improvements to Survivability Factors may be made that would reduce the number of fatalities.

Of the thirty nine accidents analysed in-depth the causes of death were assessed for all fatalities. This data set involved 3564 persons of which 1055 sustained fatal injuries. The proportion of occupants sustaining fatal injuries assessed as avoidable and non-avoidable is shown diagrammatically in Figure 6. It may be seen that for approximately one third of the fatalities no survivability factor improvements were identified which would have prevented their deaths.

4.1.3 Survivability Chains

A mathematical model has been developed such that the overall effect on survivability may be assessed from improvements made to survivability factors. Since the survival conditions often vary in different parts of the aeroplane each accident is divided into Scenarios. An Accident Scenario is defined as:-

> *" That area of the aircraft in which the occupants have a similar risk of sustaining fatal or non-fatal injuries"*

For some Accident Scenarios the improvement made to survivability will not be as evident as may at first be thought. For example for an accident where fatalities occur due to impact and subsequent fire, improvements in survivability factors relating to impact could result in:-

a) more fatalities from fire related causes, albeit with an overall improvement in the number of survivors

b) a reduction in the number of non-fatal impact injuries with a consequential enhancement of occupant mobility and hence avoidance of the subsequent fire hazard.

The model developed for this project uses the principle of a "Survivability Chain" and assumes that the occupants may be subjected to a series of independent threats (impact, fire, drowning, etc.). The model used to obtain the results presented in this paper caters for a) above but does not take into account b) (i.e. the effects of non-fatal

impact injuries on occupant mobility). However the U.K. C.A.A. is funding further work to produce a model that caters for this factor.

The concept of the Survivability Chain is illustrated in the example shown in Figures 7 & 8. Figure 7 shows the survivability Chain for an accident scenario involving one hundred occupants. The accident investigation reveals that 20 occupants sustained fatal injuries as a direct result of the initial impact and a further 10 fatalities resulted from asphyxiation due to the ensuing fire.

If improvements were made to the Survivability Factors relating to Impact then less fatalities would die of Impact Trauma. However the survivors of this hazard would still be subjected to the remaining hazard of asphyxiation and hence it is feasible that more fatalities would result from this cause of death. Figure 8 shows how the increase in number of survivors resulting from improvements to survivability factors may be assessed using the Survivability chain concept.

In this example it is assessed that the increase in occupant survivors resulting from improvements in Impact related Survivability Factors changes from 80 to 88. This however means that an additional 8 occupants are subjected to the hazards of asphyxiation. It may be simplistically assumed that the casualty rate from asphyxiation remains unchanged from that in the original accident i.e. 10 fatalities for every 80 occupants exposed to the risk. On this basis it may be expected that 10/80ths of the survivors of the impact may succumb to death by asphyxiation. For this example this would result in:

$$\frac{10}{80} \times 88 = 11 \text{ fatalities}$$

Hence the total number of survivors increases from 70 to 77. It may be seen that although the improvement results in an additional 8 survivors from the impact the overall improvement is only 7 because more people are subjected to the hazard of asphyxiation.

For each of the accidents analysed in depth the survivability factors, as listed in Appendix 1, were identified which might influence occupant survivability. In most cases the factors would have a positive effect in reducing the number of fatalities but in some instances improvements intended to increase survivability for a particular accident circumstance might have an adverse effect in another.

4.1.4 Statistical Modelling

From the in-depth analysis of 39 accidents the Survivability Chain and Survivability Factors which could have an ameliorating effect on fatalities have been identified for each scenario. Although it is not possible to predict accurately the exact reduction in fatalities due to improvements to Survivability Factors a reasonably accurate assessment may be made of the range of improvement. An estimate of this range has been carried out for each of the relevant Survivability Factors in each Scenario. The assessment results in a prediction of the highest, mean, and lowest number of fatalities that could reasonably be expected from each of the improvements.

It is then assumed that there is a 100% confidence that the fatalities will lie in the range from the highest to the lowest prediction with a 50% confidence between the lowest and the mean.

The software has been developed so that for each Survivability Factor random selections may be made within this distribution of the estimated number of fatalities. From this a re-evaluation of the number of survivors attributable to each Survivability Factor may be made for all of the accidents studied. This is then compared with the actual number of survivors.

This prediction has been made one thousand times for each accident scenario and for each survivability factor. Each time with a new random selection of the number of fatalities within the predicted range. From the resultant distribution the median reduction in the number of fatalities and the 95 percentile range may be determined.

This assessment to the improvements in fatality rate was carried out for the accidents on the basis of the aircraft standard at the time of the accident and entered onto the computer database.

Each accident was then reanalysed taking into account the improvements that would have been made to numbers of survivors if the aircraft had been configured to the latest requirements. The standard of requirements used to reassess the accidents were those contained in JAR OPS 1 and the proposed JAR 26 (1994 Draft). The effects on survivability that might be realised from improvements to the survivability factors was then reassessed. Figure 9 shows the median and range of fatality rate improvement resulting from improvements to each of the survivability factors.

Whilst it is recognised that the models are not perfect representations of an accident nor are the statistical assessments totally accurate they will provide a better assessment of the likely effect of improvements to Survivability Factors than would otherwise be derived from a simple estimate of the resultant change in number of survivors.

4.1.5 Comparison of results with other related research activities

As a benchmark test on the process employed a comparison has been made between the assessment of change in fatality rate, based on the work carried out in this project, with the predictions resulting from other previous research activities for two of the survivability factors. The two factors considered were Smoke Hoods and Cabin Water Sprays.

Smoke Hoods

For this study it was assumed that the smoke hoods did not utilise a breathable gas system and were at least as accessible as life jackets. It may be seen from Figure 9, Survivability Code 28 that the prediction of reduction in fatality rate, afforded by the use of smoke hoods, suggests that the highest value is .011 and the median value is .006.

From work carried out by the FAA and CAA (ref. 2 and 3) it was concluded, from a survey of 20 fire related accidents, involving 3,058 persons that 80 lives were to be saved (if the aircraft were configured with lavatory fire extinguishers) by the use of smoke hoods assuming 100% usage and no donning delay.
This may be shown to result in a reduction in fatality rate of:-

.011

and if account is taken of the likelihood of smokehood usage:-

.007

It may be seen that these assessments correlate well with the fatality rate improvements predicted for smoke hoods based on the work undertaken on this project.

Cabin Water Sprays

From work carried out by the CAA (ref. 4) it was concluded that 3,705 lives were to be saved by the use of Cabin Water Sprays based on an analysis of 95 fire related accidents involving 9,723 occupants.

The reduction in fatality rate from the use of Cabin Water Sprays when considering all accidents (fire and non-fire related) may be shown to be:-

.016

It may be seen from Figure 9, Survivability Code 29, that this assessment correlates well with the fatality rate improvements predicted for cabin water sprays based on the work undertaken on this project.

It should be noted that for the purposes of this study, it was assumed that the cabin water spray system would remain operable following a fuselage rupture and that it was capable of initiation by either the flight crew or the cabin attendants.

4.1.6 Assessment of Difficulty of Implementation of Survivability Factors

An attempt has been made to prioritise the Survivability Factors in order of their difficulty in implementation, in terms of the cost to the manufacturer and operator, the cost of ownership, and the difficulty in terms of development of the solution. The results of this prioritisation have been derived for the following circumstances:-

i) implementation on in-service aircraft
ii) implementation on future designs

Based on assessments made by a small group of engineers, having experience in the design, certification and operation of civil aircraft, each of the survivability factors was ranked in increasing difficulty of implementation taking into account the following aspects:-

i) the difficulty and cost of researching and developing solutions
ii) the cost of implementation
iii) the impact on aircraft operating costs.

Whilst this assessment is totally subjective each of the Engineers involved made the assessment independently and the final ranking was based on the median value of their predictions.

4.2 Analysis Results

By comparing the estimated change in fatality rate against difficulty of implementation an assessment may be made of the survivability factors that might yield the most effective improvements in survivability.

Based on the analysis work described in Section 4.1 a comparison between change in Fatality Rate, resulting from Survivability Factor improvement, and difficulty in developing and implementing solutions has been carried out. This comparison has been made after taking into account the changes in aircraft standards afforded by later requirements and hence represents the current potential for improvement.

Figures 10 and 11 show the results of this assessment for in-service aircraft and future designs respectively.

The vertical axis represents the assessment of the change in fatality rate resulting from an improvement in the related Survivability Factor as annotated. For each Survivability Factor the range of assessed improvement is shown, similar to that previously depicted in Figure 9. The horizontal axis is simply the ranking of the assessment of difficulty in developing and implementing solutions as described in Section 4.1.6.

Both Figures 10 and 11 have been divided into three zones as follows:-

i) Preferred solutions - where the improvement in fatality rate is likely to be favourable compared to the difficulty in developing and implementing solutions.

ii) Requires further assessment - representing that zone where further detailed analysis would be required to determine whether improvements to this Survivability Factor warrant prioritisation for research and development activities.

iii) Solutions unlikely to be practicable - where the improvement in fatality rate is not likely to be favourable compared to the difficulty in developing and implementing solutions.

These zones have been allocated in a totally subjective and arbitrary manner and serve only as a guide towards prioritisation.

Whilst further work is required to be definitive about the most cost beneficial solutions to improvements in occupant survivability the work carried out in this study indicates certain factors are likely to generate better solutions than others.

Preferred Solutions

As may be seen from Figures 10 and 11 the Survivability Factors likely to yield the greater improvements in survivability in relation to their difficulty in developing and implementing solutions are:-

17 Passenger Awareness of Exit Routes

This survivability factor is considered worthy of further research since it is assessed that its life saving potential is likely to be favourable compared to the difficulty in developing and implementing solutions for both in-service aircraft and new designs.

Whilst there are undoubted improvements offered by the introduction of escape path marking they may not be readily visible to passengers in certain accident scenarios and they do not necessarily lead the passenger to an available exit. The use of aural devices at the exits activated on door opening could obviate both of these problems.

The means by which this could be achieved requires further research but consideration should be given to the fitment of such devices on Type III and Type IV emergency exits and doors fitted with assist means (such that the audible device is activated when an armed door is opened). The method of operation on exits having the same method of opening in normal and emergency modes requires further consideration since automatic operation of such a device may be difficult to achieve, and if such devices were fitted they are likely to require manual initiation.

18 Emergency and Evacuation Drills

Improvements in this survivability factor are largely independent of whether they are implemented on new or in-service aircraft. Based on the work carried out on this project it is considered that an evaluation of flight and cabin crew procedures would yield beneficial improvements in survivability. Such an evaluation should take into account the lessons to be learnt from previous accidents to provide improved drills on all transport category aeroplanes. Improvements in this survivability factor are only likely to be fully effective if changes to Emergency and Evacuation drills are complemented by enhanced crew training procedures.

3 Seat/Floor Strength

The work carried out in this project suggests that improvements to seat/floor strength, even beyond the standard of the recently revised requirements, are likely to result in worthwhile improvements in survivability when applied to future aircraft designs.

The model used in the study did not take account of non-fatal injuries sustained from impact, and the resultant effects on occupant mobility. Fatalities to injured occupants resulting from their inability to escape fire or drowning have therefore not been included in the assessment and therefore the reduction in fatalities resulting from improvements in this survivability factor are likely to be greater than suggested in Figures 10 and 11.

The practicability of making these improvements on in-service aircraft would require a further study, however for new aircraft the cost/benefit analysis is likely to result in a positive conclusion for this survivability factor.

Solutions requiring further assessment

As may be seen from Figures 10 and 11 the Survivability Factors requiring further assessment to ascertain whether they can be considered as worthwhile improvements to survival are as follows:-

21 Crew Awareness of Threat

Proposals have been made that video cameras should be installed to enable flight crews to monitor areas immediately adjacent to the aircraft. As may be seen from Figure 9 the confidence band in the predicted change in fatality rate resulting from improvements in this survivability factor is large, and hence further research would be required before any firm conclusions could be reached. However changes of this kind are considered more suited to new designs rather than in-service aircraft.

2 Occupant Restraint (Adequacy of Seat Belts)

Whilst requiring further assessment prior to drawing any firm conclusions for in-service aircraft, it is feasible that improvements to this survivability factor may show a positive result from the cost-benefit analysis for future aircraft designs.

As stated for survivability factor 3 - Seat/Floor Strength, the model used in the study did not take account of non-fatal injuries sustained from impact, and the resultant effects on occupant mobility. Fatalities to injured occupants resulting from their inability to escape fire or drowning have therefore not been included in the assessment and therefore the reduction in fatalities resulting from improvements in this survivability factor are likely to be greater than suggested in Figures 10 and 11.

No attempt has been made to be definitive about the methods that may be used to improve occupant restraint since it is considered that research in this subject should not be confined to any particular area, but all means evaluated for their effectivity.

29 Cabin Water Sprays

Improvements to this survivability factor are unlikely to be practicable on in-service aircraft. However from the work carried out on this project it is feasible that worthwhile benefits might be achieved on future designs.

5 CONCLUSIONS

5.1 Whilst further work is required to arrive at any firm conclusions it would appear that accidents involving Fire, Asphyxiation or Drowning have differing fatality rate characteristics to those in which time is not a factor in survival (i.e. Impact and Mechanical Asphyxiation).

5.2 Of the survivable accidents analysed the mean fatality rate is in the region of .3 and of these approximately one third are considered unavoidable given the particular accident circumstance. Prevention of these fatalities is likely only as a result of accident avoidance rather than by improvements to Survivability Factors.

5.3 The five year moving average fatality rate for all accidents on the database exhibits a reduction in fatality rate in the mid '80s followed by an increase at the end of the decade. Accidents in which there was no fire or ditching exhibit a significantly lower fatality rate than the norm with no significant variation over the past twenty years. With the exception of this category no significant variation in fatality rate with calendar time can be attributed to either accident circumstance or aircraft size/configuration.

5.4 The work carried out in this project suggests that the Survivability Factors likely to yield the greater improvements in survivability in relation to their difficulty in developing and implementing solutions are:-

i) Passenger Awareness of Exit Routes

ii) Emergency and Evacuation Drills

iii) Seat/Floor strength

and that the following Survivability Factors require further assessment prior to any firm conclusions being reached as to whether they would yield worthwhile improvements to survival:-

iv) Crew Awareness of Threat

v) Occupant Restraint (Adequacy of Seat Belts)

vi) Cabin Water Sprays

Factors iii) to vi) are more likely to prove favourable on new aircraft designs.

5.5 Greater accuracy in the prediction method would be achieved if

i) The mathematical model described in Section 5 is developed to take account of passenger immobility due to sustaining injuries as a result of impact.

ii) A larger sample of accidents is analysed.

iii) A more detailed assessment is made of the difficulty of developing and implementing the solutions

However the predictive methods employed, and the number of accidents analysed, in this project are considered to give a reasonable indication of the Survivability Factors that are most likely to yield the cost beneficial results in terms of improvements to Cabin Safety.

6 RESULTS

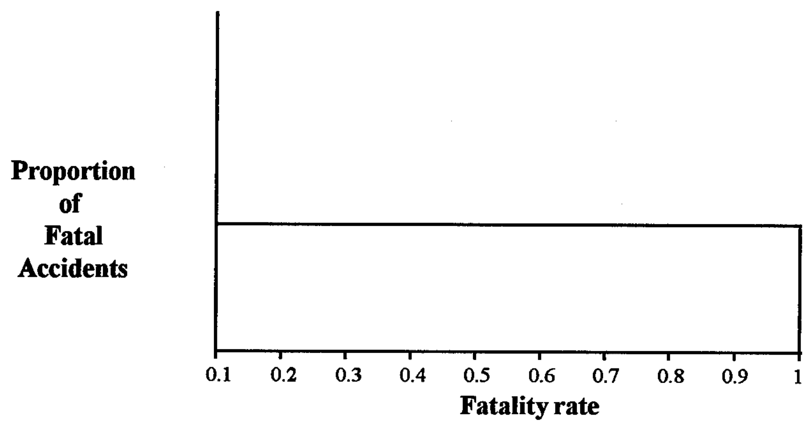

FIGURE 1 FATALITY RATE PROBABILITY DENSITY FUNCTION FOR RANDOM FATALITIES

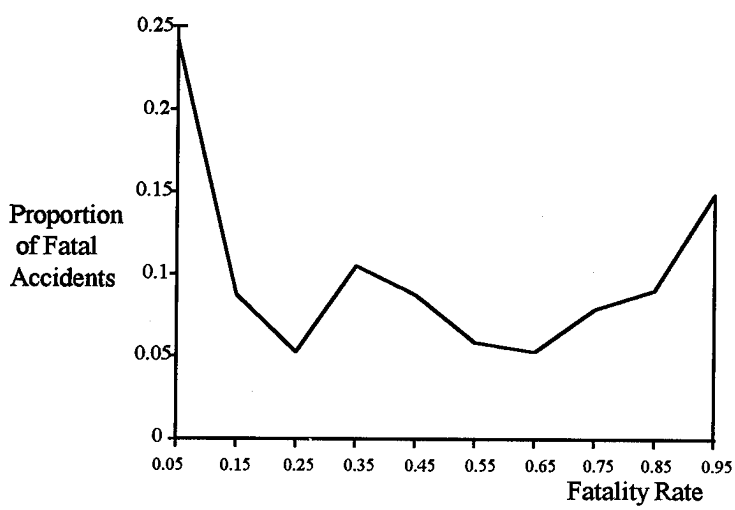

FIGURE 2 FATALITY RATE PROBABILITY DENSITY FUNCTION FOR ALL ACCIDENTS ON THE DATABASE

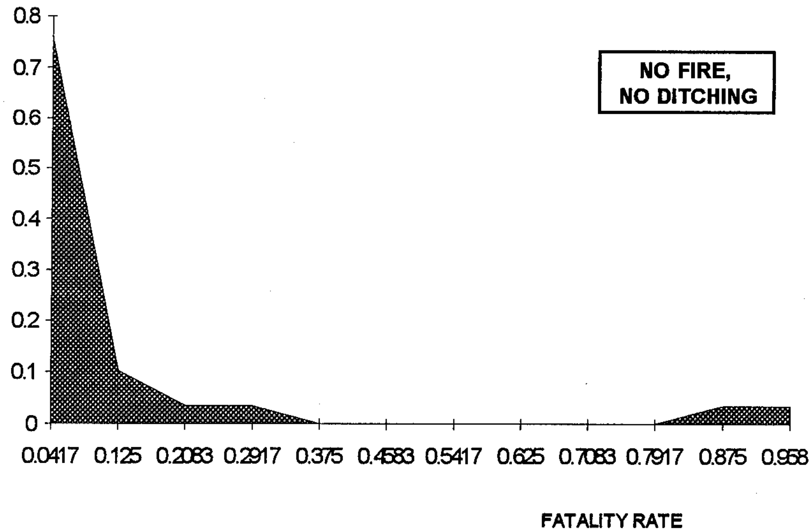

FIGURE 3 FATALITY RATE PROBABILITY DENSITY FUNCTION FOR ALL ACCIDENTS ON THE DATA BASE NOT INVOLVING FIRE OR DITCHING

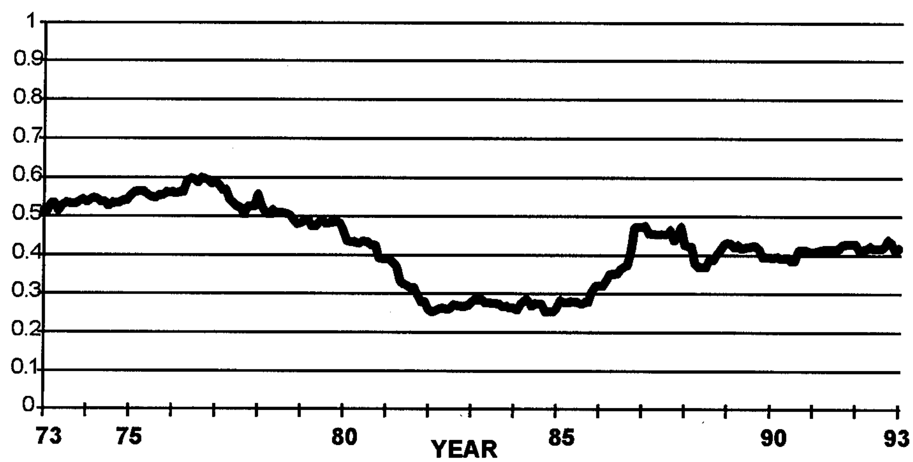

FIGURE 4 FIVE YEAR MOVING AVERAGE FATALITY RATE - ALL FATAL ACCIDENTS

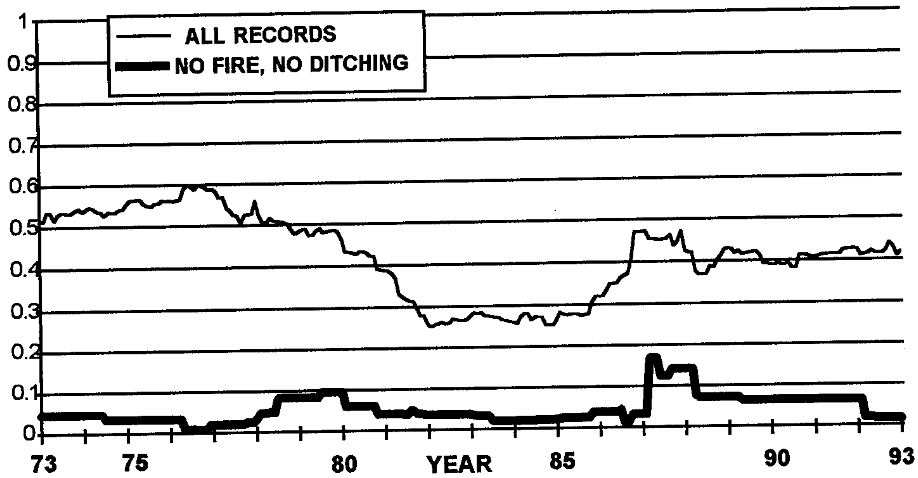

FIGURE 5 FIVE YEAR MOVING AVERAGE FATALITY RATE - NO FIRE, NO DITCHING

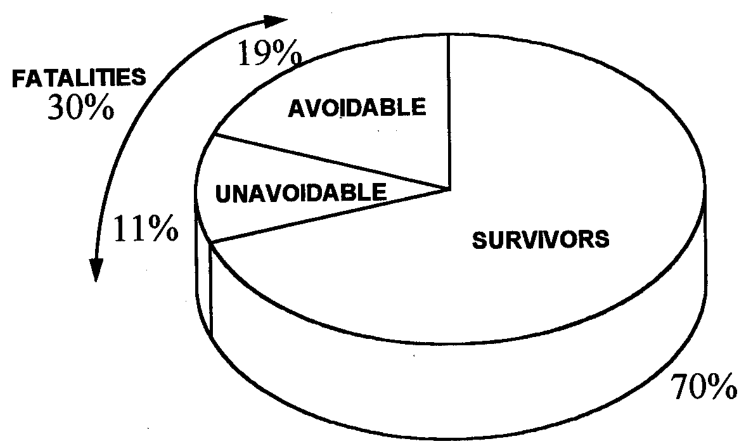

FIGURE 6 PROPORTION OF FATALITIES IN A SURVIVABLE ACCIDENT

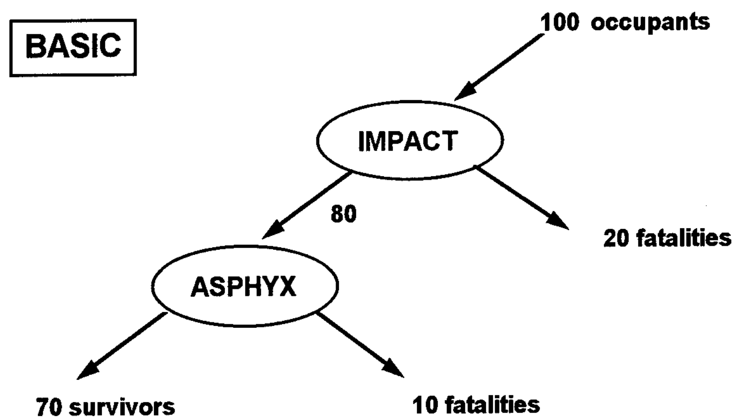

FIGURE 7 EXAMPLE OF SURVIVABILITY CHAIN

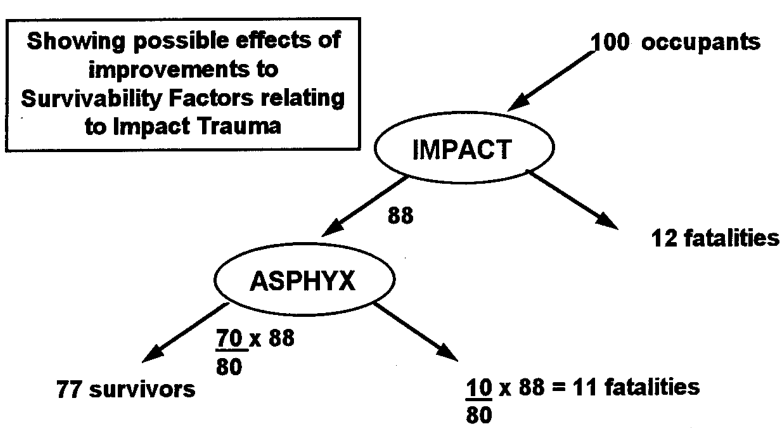

FIGURE 8 EXAMPLE OF SURVIVABILITY CHAIN

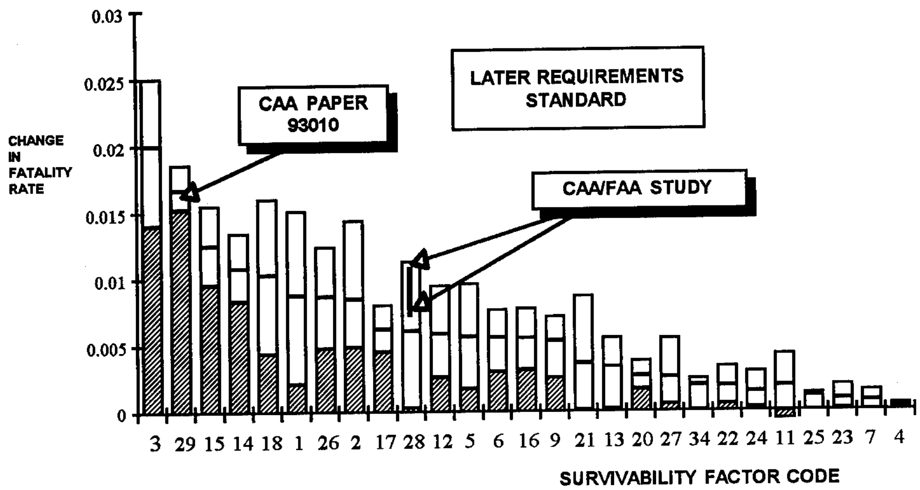

FIGURE 9 CHANGE IN FATALITY RATE RESULTING FROM SURVIVABILITY FACTOR IMPROVEMENT

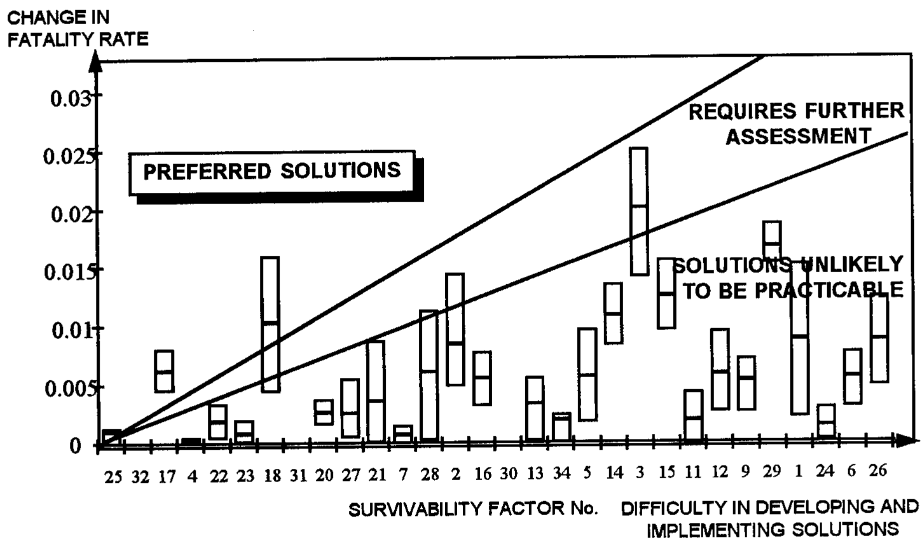

FIGURE 10 PRIORITISATION OF SURVIVABILITY FACTORS - IN-SERVICE AIRCRAFT

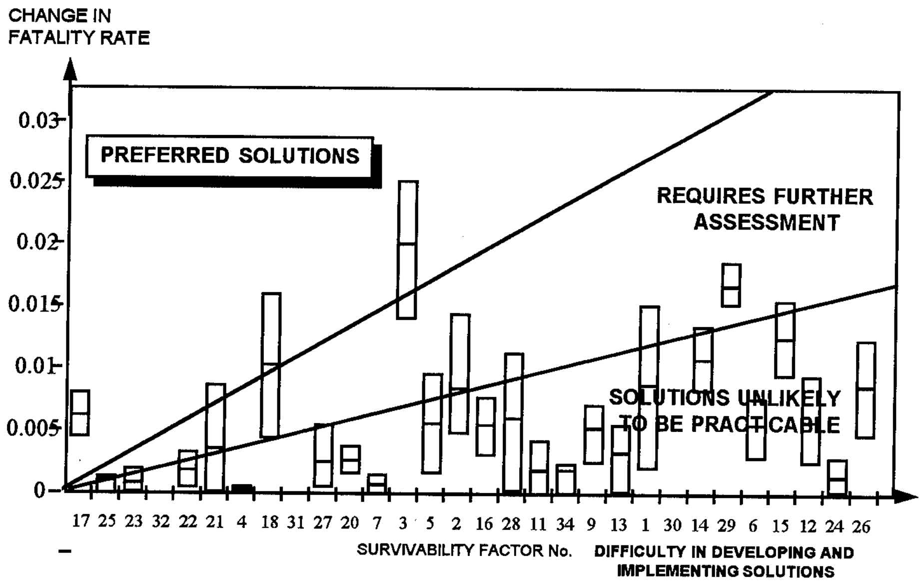

FIGURE 11 PRIORITISATION OF SURVIVABILITY FACTORS - FUTURE DESIGNS

7 ACKNOWLEDGEMENTS

This study has been carried out with significant contributions from Kevin Warren and Karen Monk who have both played major roles in its completion. The U.K. A.A.I.B. and C.A.A. have also been of great assistance. In particular Mr. Andrew Robinson of the A.A.I.B., Mr. Nicholas Povey of the C.A.A. and the staff of the A.A.I.B & C.A.A. Libraries have been extremely helpful in supplying accident data.

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APPENDIX 1

SURVIVABILITY FACTORS

No.	SURVIVABILITY FACTORS
1	Rearward Facing Seats
2	Occupant Restraint (Adequacy of seat belts)
3	Seat/Floor Strength
4	Infant Seats
5	Strength of Overhead Stowage
6	Struct. Strength of Cabins (Ditching/Impact Res. etc.)
7	Adequacy of Flotation means
8	(Not used)
9	Exit Operability
10	Flight Attendant External Visibility
11	No. of Flight Attendants
12	Adequacy of Airfield Emerg. Serv.
13	Exit Route Accessibility (Floor Level Exits)
14	Toxicity of Materials
15	Flammability of Materials
16	Head Strike Adequacy
17	Pax awareness of Exit Routes
18	Emergency & Evacuation Drills
19	(Not used)
20	Slide Operability (inc. Slide/Raft)
21	Crew Awareness of threat
22	Flight/Cabin Crew Communication
23	Cabin Crew/Pax Communication
24	Burnthrough of cabin
25	Smoke Drills
26	Exit availability (no. of exits)
27	Flotation means access
28	Smoke Hoods
29	Cabin Water Sprays
30	Exit Route Accessibility (Non Floor Level Exits)
31	Floor Proximity Marking
32	Toilet Smoke Detectors
33	(Not used)
34	Systems Crashworthiness (Oxygen, Hydraulics, etc.)

DEVELOPMENT AND PLANNED IMPLEMENTATION OF CABIN/FIRE SAFETY INFORMATION DATABASE

Lawrence T. Fitzgerald

Fire Safety Section
Federal Aviation Administration Technical Center
Atlantic City International Airport, New Jersey

ABSTRACT

The cabin/fire safety information database (CSID) was conceived from the Proposed Cabin Safety Research Program (DOT/FAA/AR-95/14). This program was proposed and developed by the combined efforts of the Joint Aviation Authorities (JAA), Transport Canada Aviation (TCA) and the Federal Aviation Administration (FAA) to address the international concerns on cabin safety and provide a mechanism of cooperative and joint research. The cabin/fire safety information database will provide a critical tool of obtaining data pertaining to cabin safety. Ultimately, the database will contain a world wide list of reports on testing, accident/incident reports, and data relating to aviation. This paper contains a description of the development of CSID.

INTRODUCTION

The success of the proposed cabin safety research program hinges on its ability to readily obtain information from a variety of sources worldwide. CSID, currently under development, is the foundation which will provide an accurate and convenient link to this information as it pertains to cabin safety. Although, all the data is now available from a variety of sources, there is no one link that provides the researcher with the whereabouts of these sources. This major shortcoming creates a very time consuming and frustrating venture for the user to gather the information for a specific task. This current trend can lead to incomplete data (missing a source), duplication of effort, added labor and unnecessary research. The main purpose of the database is to provide a tool for researchers to access as much data as they require (i.e. reports, proceedings, test result etc.) to determine the path or priority of the project under consideration. It will also be used for projects currently in progress.

Another critical aspect of CSID is the data it will provide for the utilization in future computer modeling projects. The aviation authorities currently have projects involving evacuation modeling and risk analysis. The success of these projects depend on the enormous amounts of data that is required for their operation. To support cabin safety risk analysis and other modeling methods, this database will contain an information base of accidents, incidents, historical data and trends. This database will provide the information or a link to the information required for these modeling project currently under development and any future analysis projects.

METHOD

The development CSID is a multi-phase entity, which will never come to completion. It will constantly be updated and upgraded as more information is made available and technology improves. The first phase is to organize the reports from the various organizations world wide. The organizing of these reports is the basis of the database. These reports provide a source of information of the research that been conducted in the area of cabin/fire safety. This information

alone will assist in the goal of the proposed cabin safety research program of prioritizing and assigning projects.

Phase two is the organizing of accident/incident data. This data can consist of reports on the accident, articles from publications, photos and any information that pertains to the accident/incident. There will be extensive cross-referencing to reports that pertain either directly to the accident or research conducted from the accident. This phase is critical for obtaining information on future issues and obtaining data for research. This data will be utilized in modeling and can also be used to determine trends.

Phase three and probably one the most difficult and time consuming to obtain is aviation information. This means information on flight data (number of flights, capacity, hours, etc.). This will also include airplane information (type, capacity, crew, etc.), projections, passenger data and any data that relates to the cabin, which can be utilized for research. Although this data is available, it become spread out over various sources. Obtaining this and putting it in a useful form is a challenge. This information is critical for modeling and risk analysis. Without this information the results obtained can be suspect.

Phase four is the creation of a graphical database that will link to CSID. All information in this database will support the reports and/or accident data in CSID. Data will consist of graphical drawing of test methods, some video and photographs of test conducted in cabin safety, possible video coverage of accidents/incidents, public relations media on cabin safety, etc. This database is in the planning stages and its objective is not finalized and can be amended. Again, this is another source of information that will supplement data that the researcher will utilize.

PROCEDURE

Originally, this database was to be made available to the public through a dial up service, a bulletin board. Users would be given USER ID's and Password, login and follow the instructions to search the database. The advantage to this system is the ability to monitor it use and have total control over the database. However, some of the disadvantages were:

1) A limited number of phone lines creates a situation where user access can become restrictive.

2) User must already know about the database and find the phone number. The fall back to the adage : the data out there but you have to find it.

3) Can tie up the phone line.

4) This can limit public use. Although available to public, the average user probably would not be aware of its existence.

5) No local access lines for distant users.

These restrictions can be minimized or even eliminated by creating a database on the internet or world wide web (See figure 1). This creates a true public use information system (Which may be good or bad). Anyone "surfing" or searching the internet can find this database system. Currently, it is already available on all continents and its userbase is expanding daily. This creates access to CSID that is truly international.

The internet provides us with a tool to get out the data to anyone with a computer and internet access. There are few disadvantages for the user, some of which are 1) slow access during peak loads and 2) organization of information not concise creating problems finding sources. Some of the disadvantages from the point of view of the maintaining organization are 1) Do not have as much control of the system and of the user base, 2) by today standards, the database search engine is relatively unrefined. As the internet is developed and refined these problems will probably be resolved.

Currently, the Fire Safety Section of the FAA has a home page on the internet (see Figure 2). A home page is terminology used on the internet to described a starting point for the information the developer plans to submit. (similar to a title page and introduction in a book).. This home page provides an overview of the programs that the fire safety section is responsible for, also included is information on upcoming conferences, workgroups and meetings.

This home page is where the access to the planned database begins. This is a basic designed page as initially will be the database page. The pages on the net are created using the Hypertext markup language (HTML), with current plans to use Practical Extraction and Report Language (PERL) to create the database access.

The database page will employ a simple search routine utilizing keywords that the users submits. The search will return all matches containing the user input keyword. Each search is displayed on a separate page which the user can scroll down to view. The search page will display the following information about reports: Report No., Title, Date, Author(s), a short abstract and information where to obtain a copy of the report.

Please note that the information supplied by CSID is just a synopsis of the reports of a particular subject and not the entire report. This is a database designed to allow the user to view what information is available and to inform the user as to where the information can be obtained. The cabin safety library, which maintains the database does not supply these reports. All reports are not available at the Federal Aviation Administration Technical Center. Whenever possible, information will be presented to the user of where the report can be obtained.

The user can continue the search process by simply returning to the CSID search page and entering new keyword and requery.

OTHER OPTIONS

As this page develops, the page will under go numerous updates and changes, both cosmetically and structurally. As the phases are complete, the home page will reflect this with a new search page. The user will be able to search through the report database, accidents database, view graphics and eventually someday to download portions of video relating to reports. The user will be able to obtain historical data and projected data through the aviation information database. All of this information will be maintained by the Cabin/Fire Safety Section at the Federal Aviation Administration Technical Center.

Another very powerful feature of the internet is the ability to provide links to other pages on the internet. Since it is virtually impossible to have access to all relevant data at one location, a click of a button can link you to a location where pertinent information can be found. As an Example, there is a aviation home page on a server at Harvard University where SDR's (Service Difficulty Reports) can be located. Another location where FAR's (Federal Aviation Regulations). These links are virtually transparent to the user. There are virtually thousands of links, and as more links relative to the Cabin/Fire Safety database become available, or discovered, they will be reviewed for relevance and a link will be created on the Cabin/fire safety home page.

An Additional option being considered at this time, is the ability for the internet user to submit fundamental information of reports that the user considers relevant on the topic of cabin safety. An internet form will be made available on the CSID page for users to submit their information for review and possible inclusion in the database.

There is always an option to Email me, suggestions, problems and questions relating to the home page and the database.

LARRY_FITZGERALD_AT_FAA.GOV@CT27

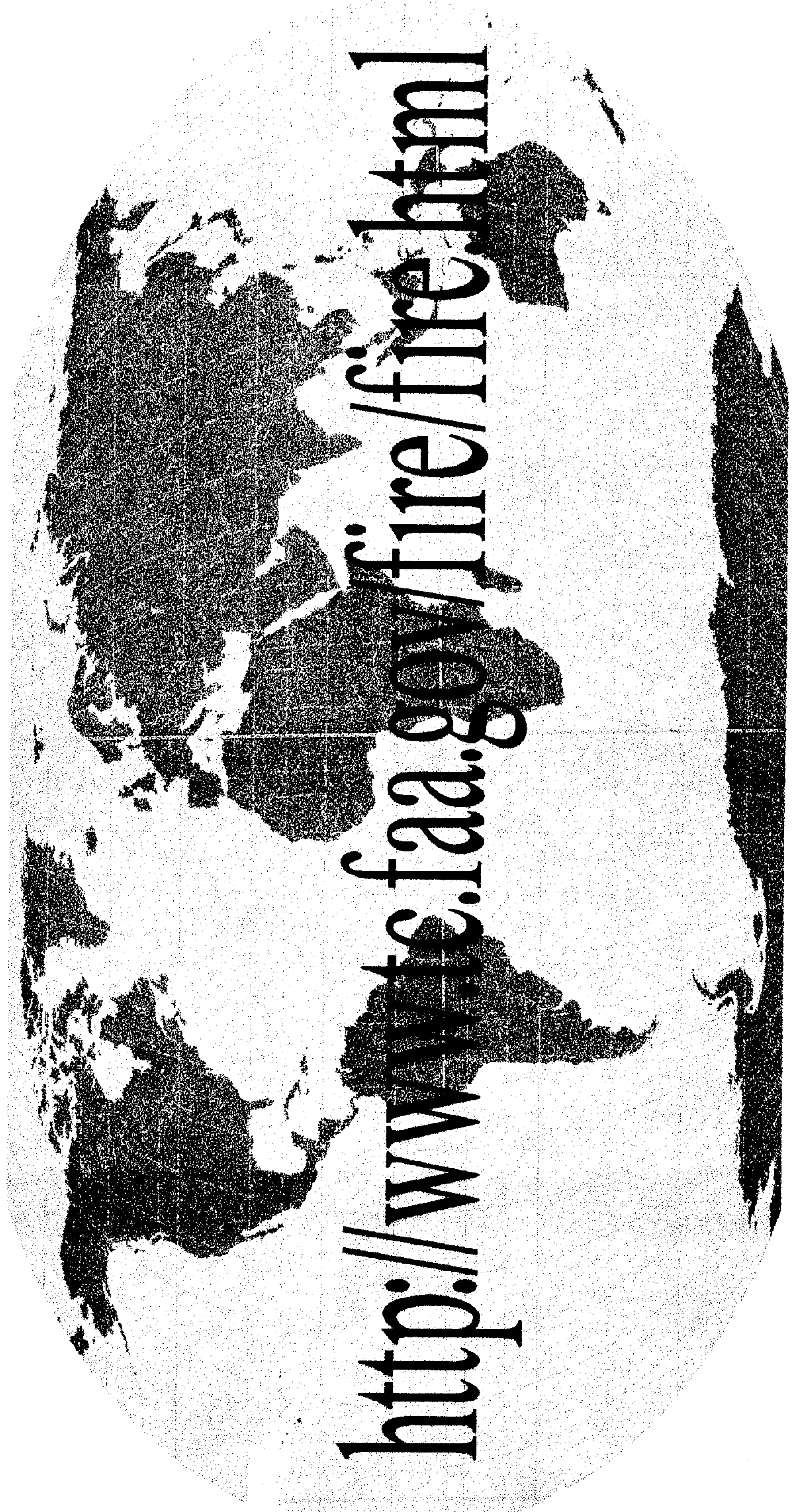
TIMETABLE

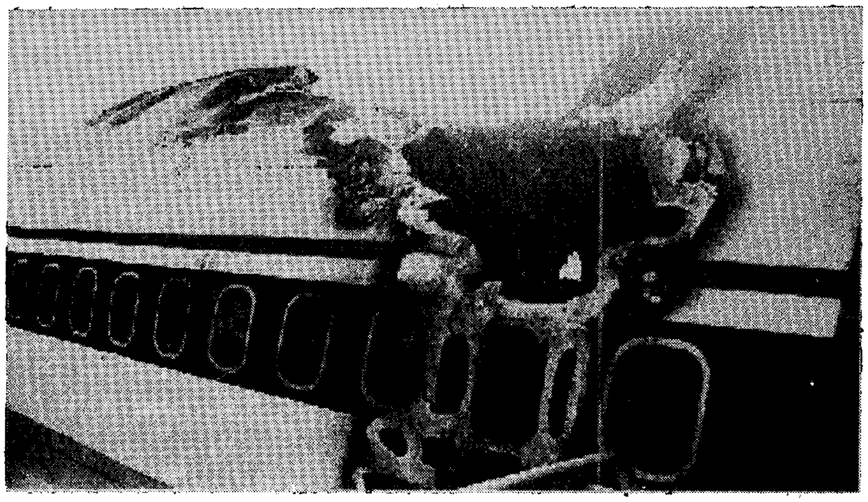
Phase one is currently being organized and developed and will be installed in approximately 2 months. This will be a condensed version of the database with a simple search routine. The majority of reports included in the database at this time will be reports currently on file at Cabin/Fire Safety Library. This will be the beginning of the implementation of phase 1, with data continuously being updated from that point forward.

Phase two will follow shortly after the implementation of phase one. Phase two will be developed concurrently with phase one.

Phase three will be an ongoing development that will continue as data sources arrive and reviewed. Some information on phase three might be available on different links. If and when this information become known, a link will be set up on the Cabin/Fire Safety Home Page.

Phase four will follow accordingly. As the technology for the internet improves and also as the CSID database upgrades to handle video, the implementation will be reviewed at that time and a course of action will be taken.


http://www.tc.faa.gov/fire/fire.html



Fire/Cabin Safety Overview

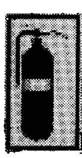
Proposed Cabin Safety Research Plan : The objective of this plan is to enhance the effectiveness of cabin safety research and development (R&D) by establishing an international framework. This allows for systematic joint identification, prioritization and coordination of needed R&D. This plan integrates the pertinent activities within the Federal Aviation Administration (FAA), Joint Airworthiness Authority (JAA) and Transport Canada (TCA).

Research Topics, performed by the Technical Center, under the proposed research plan:

Cabin Safety Risk Analysis : A risk analysis model and computer program to compute the risk to airline passengers arising from cabin accidents/incidents and the reduced risk and benefit assuming the implementation of various cabin safety improvements.

Upcoming Conferences and Working Group meetings :

International Conference on Cabin Safety Research

International Halon Replacement Working Group

Aircraft Materials Fire Test Working Group

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For Questions about this page please contact re: Larry Fitzgerald (Larry_Fitzgerald_at_CT27@admin.tc.faa.gov).

EVACUATION SESSION

Tuesday, November 14, 1995

Session Chairman
Jean-Paul Deneuville
STPA/N
Airworthiness Department

ABSTRACT

"Airlines Perspective on Evacuation"

Kirke Comstock
United Airlines
San Francisco, California, USA

The main areas discussed in this paper are: Existing Research Basis: survivable crash and burn, dynamic crash environment, and crew performance; Lessons Learned: jets/turbines more reliable than props, crew training more realistic (CRM), ATC more disciplined, cabin crews more experienced, passengers more blasé, accident database no longer meaningful--future trends are more/less? explainable; What To Do?: 1) we cannot design much more into the system, 2) current trends should continue--zero accidents is not an unrealistic goal, and 3) value added in research $ will come more from human performance; Direction to Pursue: 1) activating passengers to appropriate behavior, 2) flight/cabin crew coordination, 3) well researched performance in aisles and at exits, and 4) focused and sustained development of evacuation models.

EVACUATION - AIRFRAME MANUFACTURER'S VIEWPOINT

JAMES T. LIKES
DIRECTOR OF PAYLOAD SYSTEM DESIGN
BOEING COMMERCIAL AIRPLANE GROUP

NOVEMBER 14, 1995

Introduction

Today, I'd like to take this opportunity to give you a manufacturer's perspective on evacuation systems and evacuation system testing.

In Boeing's view, the purpose of evacuation system has always been to get people out of an airplane as quickly and safely as possible in an emergency. This is the bottom line that we are all working together to achieve.

A significant amount of data exists from evacuation testing that should enable the industry to review the results and to collectively determine the direction for evacuation improvements. There is evidence to believe that, by optimizing the evacuation procedures and training, a substantial improvement in terms of reduced evacuation time is possible. The type of research for this activity should focus on making the most effective use of evacuation equipment and procedures. This has the potential to reduce evacuation time by ten (10) to twenty (20) percent.

Background

Looking back, we can see that a network of rules has been developed over time to address evacuation. These rules govern how many exits are required for the number of passengers, how long it can take to open an exit and deploy a slide, where attendant seats should be located relative to exits, and how wide aisles and passageways need to be to get people to the exits, plus many other specific items relating to evacuation. Each rule focuses on one discrete, usually measurable, portion of the overall evacuation system.

In the 1960's the question was asked, "How well do these rules work together to allow us to evacuate the airplane?". FAR 121.291 was created in 1965 to validate the crew members' ability to execute the established emergency evacuation procedures and to ensure realistic assignment of function to the crew. FAR 25.803 was created in 1967 to show the basic evacuation capability of a new airplane. Hundreds of tests have been conducted by operators, and dozens of tests by airframe manufacturers, since these rules were created.

These tests with rare exception have not led to changes in hardware design. The tests did lead to a rule change in 1978 which combined the part 25 and 121 tests. This rule change took place because the majority of tests conducted by the individual operators of each model airplane were not providing any significant amount of new information. With the inception of the airplane evacuation tests, it has been shown the individual discrete rules, mentioned earlier, when brought together in a full scale evacuation test, work as a system within the established performance standard.

However, review of test results identifies that the single biggest contributor to evacuation variation is the result of differences in evacuee management. The variations in this management of evacuees has been observed to vary from 10 - 30 seconds for essentially similar conditions. It would appear that the potential exists to make a significant contribution to evacuations, if the best and most efficient procedures for managing evacuees can be identified and used. Once identified these "best practice" procedures need to be incorporated into all training programs.

The only way anyone can understand whether the evacuation system will be able to get people out of an airplane quickly and safely in an emergency is to have good data from testing of all the elements of the evacuation. These elements need to work together, and their interrelationships must be understood before valid test data can be identified.

The evacuation issues area of the Aviation Rulemaking Advisory Committee (ARAC) was asked to look at evacuation as a whole in order to form a framework to guide the creation of performance standards for evacuation regulations. The Performance Standards Working Group (PSWG) identified seven functions that must be successfully performed to meet the goal of evacuation:

Threat assessment
Pre-evacuation survival
Information transfer
Guidance
Evacuee management
Escape
Life support

These functions are also closely interrelated, for example threat assessment occurs before, during and after the evacuation, and affects both the evacuee management and escape functions. This figure shows schematically some of the interrelationships between the functions, and when they are necessary during an evacuation.

Each of these functions is accomplished using a combination of equipment and procedures. (e.g. 16g seats and assuming a brace position both contribute to pre-evacuation survival; seatback cards and cabin attendant commands both contribute to Evacuee management.)

Data and Evacuee Management

Naturally, it has been easier to define and conduct tests of equipment. We can and do run tests of exit and slide operation under many different conditions. On the 777 there were 99 certification tests on escape slide/rafts alone. Exit sizes, aisle and passage widths have been determined based on numerous tests dating from the 60's into the 90's. One result of all this testing had been a trend toward optimizing the equipment designs.

It is inherently more difficult to define and conduct tests of procedures. People factors can and do lead to difficulties in testing and variations in results. Evacuee management, the process of guiding airplane occupants from their seats to the ground, is a key element of any evacuation. Evacuee management procedures, duties, and the related cabin attendant training are typically only proved out today under the following conditions - during a mini evacuation, a full scale evacuation certification demonstration, and during an actual in-service evacuation. Data on evacuee management is always collected during full scale demos, but it is harder to collect from actual emergency evacuations. Investigators usually can make general assessments of the progress of the evacuation, and can identify any key problem areas, but many finer points escape without the video/audio coverage commonly used for tests.

Since 1978, full scale evacuation demonstrations have basically only been conducted on new models and derivative model aircraft. By nature these demonstrations have different aircraft types or models, arranged with different configurations, using different crew members and passengers, and utilize somewhat different evacuee management procedures. These differences make it difficult to directly compare results.

Each airline has developed their own set of cabin attendant duties and training to accomplish evacuee management. There is a need for generalized fundamental procedures to cover all of the airplane types and models. This will simplify training, and reduce variations that a cabin attendant must recall during an evacuation. Evacuee management procedures and training were established and tested during the 60's and 70's. Since then, as new information becomes available from evacuations, and as styles of training change, the evacuee management procedures and training are modified. In the past 17 years, airlines have had few opportunities to assess these modifications in full scale demonstrations.

Proposed Direction for Research

Our view is that research in the area of evacuee management would be a wise investment. Research would be used to optimize the evacuee management by identifying the key actions and concerns. Cabin attendants are expected to use their basic procedures and best judgment to manage an evacuation. Research will provide information not only to enhance procedures, but to enable cabin attendants to make their best possible judgements during any evacuation.

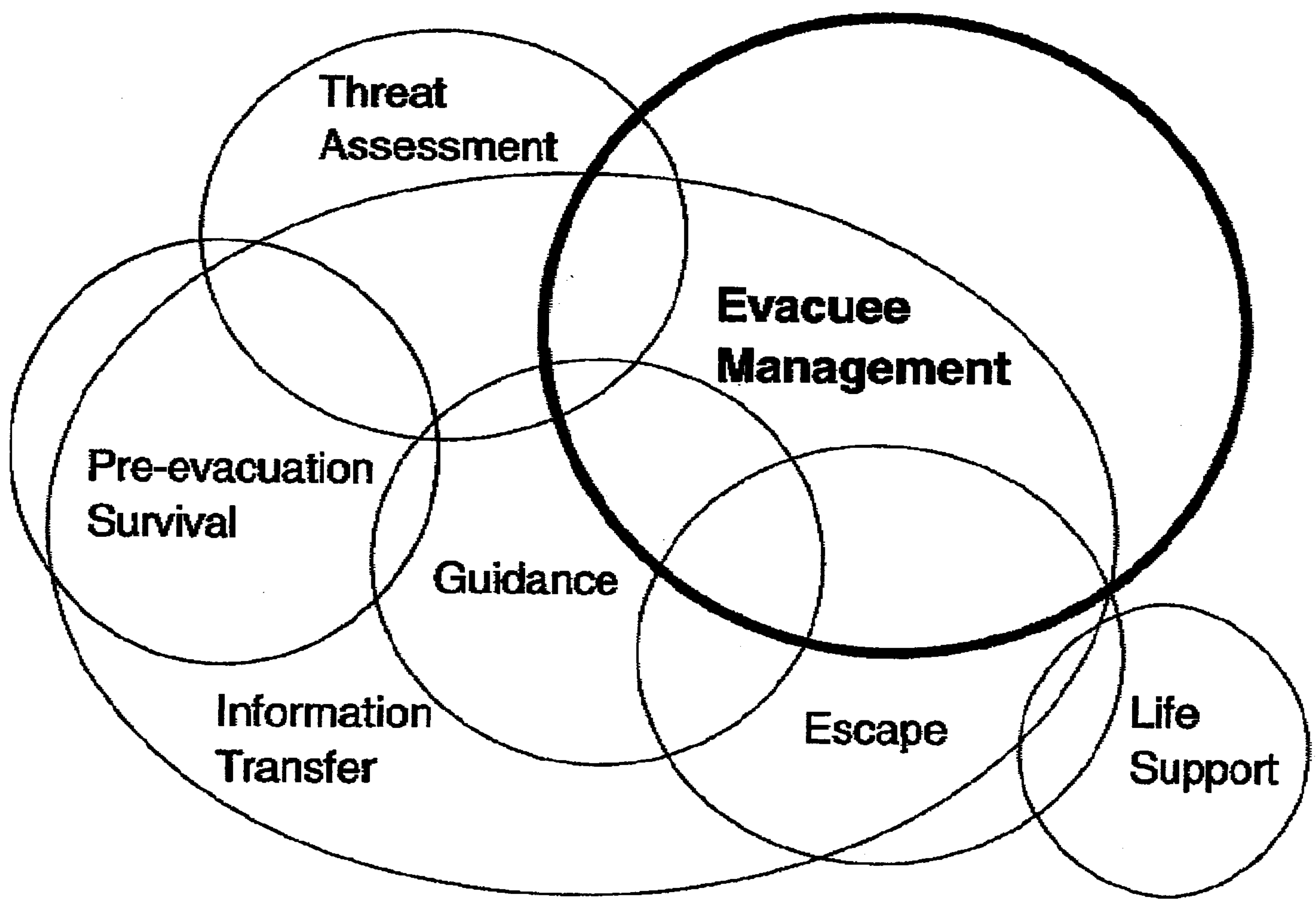
Boeing has begun work in this direction by reviewing data obtained from full scale demonstrations, and has identified several key factors that could be included in cabin attendant training to enhance evacuee management during any evacuation:

- Stress assertive actions by cabin attendants, it speeds up the evacuation.
- Keep out of passágeway, don't inadvertently impede flow to the exit.
- Understand differences in exit and slide configuration and capability to optimize their utilization.
- Importance of secondary duties as well as primary duties:
  - establishing flow away from unusable exit(s),
  - once flow established, proceeding to appropriate location to best direct passengers to active exits,
  - continuing to monitor evacuation progress at usable exits and adjacent zone(s),
  - maintaining awareness of evacuation progress, and redirecting passengers as necessary to minimize airplane evacuation time.

Conclusion

Research in the area of evacuee management is a wise investment and I believe it has more near term potential benefit than any other single item. Research supports the ARAC effort, which has identified evacuee management as one of the key elements of evacuation. The research will also be of immediate benefit to the airline industry and enhance the safety of the traveling public as we work together to get people out of an airplane as quickly and safely as possible in an emergency.

INTERRELATED EVACUATION FUNCTIONS



AREAS OF CONCERN FOLLOWING RECENT RESEARCH

Helen Muir OBE PhD
Department of Applied Psychology
Cranfield University
Cranfield, Bedford England.

ABSTRACT

Recent research which has been conducted into the factors influencing passenger safety and survival in aircraft accidents is reviewed. The influence of the airframe configuration (e.g. space adjacent to exits), safety procedures (e.g. flight attendant performance), the cabin environment (e.g. presence of smoke) and passenger behaviour (e.g. safety training) on the evacuation process is discussed. The safety issues which have emerged from the results of the research are identified.

1. INTRODUCTION

During the last decade a series of major research programmes have been conducted in the UK in the field of Cabin Safety. The work was initially sponsored by the Civil Aviation Authority (CAA) but more recently the programmes have been supported by the European Joint Aviation Authorities, Transport Canada and as part of a collaborative agreement within the UK CAA and the Federal Aviation Authority.

The factors which can influence survival in aircraft accidents can be broadly classified into four groups (ref 1).

(a) Configurational

The standard features of the aircraft cabin which may influence access to exits and hence evacuation flow rates, e.g. seating, number and location of exits.

(b) Environmental

These are the features of the cabin and external conditions which influence the survivability and evacuation time, e.g. heat and toxic smoke in the cabin, light and weather conditions externally.

(c) Procedural

This includes the effectiveness of safety procedures and drills, together with the experience and training of the crew and other rescue personnel, e.g. fire crew, which can influence the evacuation procedures.

(d) Behavioural

These include the psychological, biological and cultural attributes of individual passengers and flight attendants which influence their behaviour as individuals and as members of a group, e.g. sex, age, prior knowledge and experience, fitness, physical and mental health, etc.

The recent research which has been conducted into cabin safety at Cranfield (UK) has included projects in each of these areas.

2. AIRCRAFT CONFIGURATION

2.1. Type III Exits

2.1.1. Evacuation

In the accident which occurred at Manchester Airport in the UK in 1985, (ref 2) the evacuation of passengers was impeded by blockages at the Type III exit and at the aperture between the bulkheads at the front of the cabin. Blockages also occurred during the evacuation through the Type III exit in the accident which happened in Los Angeles in 1991 (ref 3).

Following the accident at Manchester the UK CAA sponsored a major programme of research to determine whether making changes to the seating configuration within the cabin adjacent to the Type III exit would reduce the likelihood of blockages. A major test programme was undertaken involving members of the public taking part in simulated emergency evacuations from a Trident aircraft.

The procedure for the tests differed from the procedures which had been used in previous test programmes and in aircraft certification evacuations. In an attempt to reproduce the rush which can occur for the exits in a life-threatening emergency, incentive payments, in the form of a £5 bonus, were paid to the first half of the participants to evacuate the aircraft. The tests were later replicated without bonus payments in order that a comparison could be made between the data obtained when passengers were competing to evacuate the airframe as can happen in a life threatening situation, with data obtained when passengers were instructed to evacuate as quickly as possible, as happens in an aircraft certification evacuation.

The results from the tests (ref 4) indicated that when the distances between the seat rows (involving three seats per row) adjacent to the Type III exits is increased from a three inch vertical projection to between 13 and 25 inches vertical projection, there will be an increase in the evacuation rate and a reduction in the probability of blockages. A configuration was also tested involving the outboard seat removed and a 10 inch vertical projection between the seat rows. This also gave rise to an improvement in the evacuation rate. The

results clearly demonstrate that the introduction of AN 79 by the CAA has been a significant improvement.

Recently the Association of European Aircraft Manufacturers (AECMA) have sponsored a series of extensions to this programme which has involved the same test protocol but additional seating configurations. The tests have included 6 inch and 10 inch vertical projections when three seats are positioned in the rows adjacent to the exit, and a 6 inch and 10 inch vertical projection when two seats are positioned in the row adjacent to the exit.

The objective of the test programmes was to determine the configurations which would give rise to the most rapid evacuation rate was achieved, however the fact that certain configurations give rise to a rapid evacuation rate but would appear to have an increased probability of blockage remains an area of concern.

In the tests trained members of the research team operated the hatch in order to ensure that the only difference between the test results were a function of changes to the seating configuration (previous tests had shown (ref 5) that this would be essential to produce reliable data). It is likely that there will be an interaction between evacuation rate and ease of operation of the hatch when opened by a member of the public. This would be expected since the researchers operating the hatch, have found that the configurations involving two seats in the row adjacent to the hatch make the operation more difficult.

2.1.2. Ease of Operation

Members of the public were involved in a series of tests to explore the influence of changes to the weight of a Type III exit hatch involving a 3 inch and 13 inch seating configuration adjacent to the exit. The participants in the tests involve men and women who were in the lower 50th percentile who were required to operate the hatch when they were seated next to the hatch and also when an incapacitated passenger (dummy) was seated next to the hatch. The results showed that reducing the hatch weight from 25 to 12 kilos led to a significant improvement in the rate at which members of the public can operate the hatch and evacuate onto the wing of the aircraft (ref 6).

Recently the CAA have sponsored the development and performance evaluation, of a new Type III exit hatch concept. The design has involved the development of an "up and over door" at the exit with no modification to aperture. In addition to improving the ease of operation the new design removes the problem of exit disposal during the evacuation. The report from this project will be available early in 1996.

2.2. Bulkhead Aperture

In the accident which occurred at Manchester in 1985, serious blockages had occurred at the aperture leading to floor level Type I exits. Part of the programme, reported in section 2.1.1 involved tests to explore the influence of changes to the aperture between the bulkheads on evacuation rate. The results

indicated (ref 4) that increasing the minimum distance between these units from 20 to 30 inches would lead to a significant improvement in the evacuation rate and a reduction in the likelihood of blockages. The configuration involving no bulkhead on one side of the airframe impeded the ability of the cabin crew to operate the exits and on several occasions led to the crew being pushed out of the aircraft by the initial rush of passengers. This configuration was therefore not recommended although it does exist on some aircraft with Type I exits.

2.3. Evacuations From the Rear of the Cabin

A series of tests were conducted involving members of the public, in groups of 60, evacuating from the front or the rear of a 737 simulator. The results indicated that although the overall evacuation rates tended to be a little slower when passengers were evacuating through the rear of the aircraft, the differences between the times were not significant (ref 7).

2.4. Future Considerations

2.4.1. Combined Ease of Operation and Evacuation Tests

An important next stage in the programme of evacuation research should be combined tests involving ease of operation and evacuation. In other words tests in which members of the public operate the hatch and evacuate onto the wing to ensure that the seating configurations which are included in the regulations will lead to a rapid evacuation when members of the public operate the hatch. All of the previous tests have involved the use of only one Type III exit. Since many airframes now fly with two pairs of Type III exits located near the centre of the cabin, this factor should also be included in the consideration of the design of future tests.

2.4.2. Darkness

Transport Canada have sponsored some initial tests to explore the influence of reduced lighting on the ability of passengers to evacuate the airframe. This work has to date only involved Type I exits, but additional tests involving passengers evacuating through Type III exits would enable us to obtain a better understanding of what steps can be taken to assist the passengers to reorientate and to reduce the probability of passengers falling from the wing in darkness.

2.4.3. Aisle Joggle

Transport Canada have also sponsored some initial tests to explore the influence of a "joggle" in the main aisle, on the evacuation rate. These tests are to be continued with emergency lighting in the cabin and darkness outside the cabin. The report from this project will be published in 1996.

2.4.4. Wide Bodied Airframe Tests

The evacuation tests which have been conducted in UK and by FAA (CAMI) in USA have exclusively involved narrow bodied airframes. Research should be undertaken involving wide bodied airframes to ensure that the dimensions which have been recommended for narrow bodied airframes e.g. 30 inch aperture between bulkheads, would be appropriate for wide bodied airframes. Such testing could look at other configurations such as cross-aisles and access to Type I exits.

2.4.5. Very Large Aircraft

With the development of Very Large Aircraft capable of carrying up to 1000 passengers it will be important to determine whether the airworthiness requirements specified for current airframes will be adequate for Very Large Aircraft e.g. for aisle widths and seating density. There are also operational considerations such as in-flight turbulence which may be affected by new commercial concepts, e.g. concepts such as casinos, fitness centres, duty free shops, business centres which would encourage passengers to leave their seats and put them at greater risk if turbulence or decompression is encountered.

2.4.6. Evacuations Slides

The slides continue to give rise to injuries both in accidents, in certification tests and in test programmes. Indeed it has been the occurrence of injuries during aircraft certification that has led to the demand for changes to the full scale evacuation demonstration test conducted for aircraft certification. There are no published reports of research in this area. Perhaps as one of the many new concepts which will be required for the Very Large Aircraft will be an alternative mechanism for transporting passengers from the exit to the ground.

3. AIRCRAFT ENVIRONMENT

3.1. Non-Toxic Smoke in Cabin

In the majority of accidents in which there is loss of life a fire will have occurred. In the event of a fire there is usually a period of approximately two minutes between the onset of the fire and the conditions in the cabin becoming non-survivable due to the presence of smoke and toxic fumes. Since the accident which occurred at Manchester in 1985 (ref 2), the regulatory authorities have introduced a number of regulations specifically addressing the problems of smoke and fire entering the cabin. These measures have included fire blocking of seats, fire hardening of interiors e.g panels, floor proximity lighting and smoke detectors in the toilets and cargo holds.

The CAA also sponsored a programme of evacuation tests involving the presence of dense non-toxic smoke in the cabin. In all other respects the evacuation tests replicated those which have been conducted from the Trident aircraft and are reported in Sections 2.1.1. and 2.1.3. Again the tests involved

members of the public in groups of 60, taking part in evacuations through a range of seating configurations at the Type III exit and a range of apertures between the bulkheads. Two series of tests were conducted, one involved bonus payments whilst the other required participants to evacuate as quickly as possible without bonus payments.

The results indicated that the main effect of the smoke was to lead to a significant increase in the time taken to evacuate the aircraft and that the configurations which had been shown to be optimum in clear air did not give rise to any greater increase in evacuation time than the other configurations tested. Another important finding was the value which participants placed on information gained from tactile cues during the evacuations (ref 4).

3.2. Cabin Water Spray Systems

In the UK AAIB Report following the accident which occurred at Manchester Airport (ref 2) one of the recommendations was that consideration should be given to the introduction of cabin watersprays to be used in the event of a major fire. As a number of systems had been developed and been shown to be highly effective in preventing the spread of the fire through the cabin, a test programme was undertaken to determine whether the operation of a cabin waterspray system would create problems for passengers and slow down the evacuation rate. The results from the programme indicated that there was no significant difference between the evacuation rates with and without the cabin waterspray operating (ref 8). The other findings from the test programme included the fact that participants subjective reports of visibility within the cabin were not generally found to be affected by the waterspray although those wearing spectacles were found to have more visibility problems than those wearing contact lenses or no eye wear. No potential problems with the floor surface or cabin fittings becoming wet were identified. Participants reported that the evacuation commands given by the flight attendants were significantly less audible when the spray was operating.

3.3. Future Considerations

3.3.1. Tactile Cues

Consideration be given to the introduction of additional tactile cues to assist passengers evacuating from a smoke filled cabin and ensuring that there is sufficient information for them to understand their location in the cabin when their vision is impaired.

3.3.2. Smoke Hoods

The introduction of smoke hoods was recommended in the UK AAIB report following the Manchester Accident (ref 2). Despite extensive development work by a range of companies a smoke hood has not been produced which is capable of meeting the UK CAA specification (ref 9). It must be of concern that certain companies are manufacturing and selling to the public smoke hoods about which

there is no published information on the donning time, the protection time and the fact that they have not met the UK CAA specifications. There is very limited published information about whether if worn, these smoke hoods would delay the evacuation of the passengers. In the ground fire scenario there is considerable evidence to show that delay would be fatal. The TWA L1011 incident at New York and the recent DC9 at Atlanta clearly demonstrate the need for passengers to get out as quickly as possible. Any delay to don smokehoods would lead to a greater number of fatalities.

3.3.3. External Environment

The external environment into which passengers evacuate has not historically been given consideration apart from the ditching scenario or over run into water and in which case, life jackets and rafts are available. No provision is given for passenger protection following an evacuation into a hostile environment e.g. extremes of temperature. This might be of even greater relevance if waterspray systems are introduced since once the passengers clothing had become wet by the spray, they would be severely disadvantaged in a cold environment.

3.3.4. Water Sprays

If cabin watersprays systems are to be introduced, tests will be required to determine the maximum level of noise emanating from the nozzles which ensures that this does not impede the ability of the passengers to hear the commands from the flight attendants.

4. AIRCRAFT PROCEDURES

4.1. Assertive Flight Attendants

In 1994 a programme of research into flight attendant behaviour during emergency evacuations was jointly sponsored by the CAA and FAA.

The tests involved passengers evacuating from a sixty seater 737 simulator with a range of conditions. Some groups of passengers experienced assistance from two assertive flight attendants, others experienced assistance from one assertive flight attendant, others two non-assertive flight attendants and for others no flight attendants were present to assist the evacuations. Assertive behaviour included calling volunteers to exits and actively pushing them through exits as rapidly as possible in a highly active but non-aggressive manner, non-assertive behaviour involved asking volunteers to come to exits and only giving physical assistance when someone was in danger of falling in the vestibule area. The tests were conducted with two separate procedures. During two of the evacuations participants were instructed that the first 75% to evacuate the aircraft would obtain a £5 bonus. In the other two evacuations participants were instructed that they would all receive a £5 bonus if they were able to complete the evacuation in less than 90 seconds. The results from both procedures clearly

indicated that assertive flight attendants significantly increased the speed at which passengers were able to evacuate the aircraft when compared to non-assertive or no flight attendants present (ref 7).

As the test programme developed it was confirmed that in addition to the operation of the exits, the management of passengers and crowd control skills with appropriate commands were an important function to be performed by the flight attendants.

4.2. Acoustic Attraction Signals

One of the recommendations in the UK AAIB report following the accident at Manchester (ref 2) was that consideration should be given to the introduction of acoustic signals which in the event of a fire could be used to attract passengers to operational exits.

Acoustic signals were developed, fitted in the Trident Aircraft and a series of evacuations tests with non-toxic smoke present in the cabin were conducted. The results indicated that the presence of the acoustic signals did not significantly increase the rate at which passengers were able to evacuate the aircraft (ref 10).

4.3. Future Considerations

4.3.1. Assertive Flight Attendants

The results from the evacuations involving assertive flight attendants clearly indicated the importance of training flight attendants to be assertive during an emergency evacuation. The demonstration of an ability to perform assertively in a simulated emergency should be a requirement for all students during ab-initio training before they go onto the line. Any student who cannot achieve the standard will be placing themselves and members of the public at increased risk in the event of an accident. Ultimately this may have implications for the selection criteria used for flight attendants.

4.3.2. Recurrent Training

The requirement to demonstrate assertive behaviour during evacuations should also be introduced into recurrent training. Indeed consideration could be given to future work to develop performance standards to be used for both ab-initio and recurrent training.

4.3.3. Flight Attendants and Type III Exits

The fact that assertive flight attendants can significantly increase the speed of the evacuation through Type I exits suggests that research should be undertaken to determine whether the presence of a flight attendant stationed at the Type III exits will significantly increase the speed at which passengers can evacuate through these exits. If this were shown to be the case, on those aircraft

with two pairs of Type III overwing exits this could lead to a substantial reduction in the time taken to complete the evacuation.

4.3.4. Crowd Control

There is an urgent need for further work to determine the most effective method of controlling passengers rushing towards exits in an emergency and for determining the most appropriate commands which will be understood by passengers of different nationalities.

4.3.5. CRM for Flight Attendants

Crew resource management training involving flight attendants and members of the flight deck is being introduced by some companies. The objectives, syllabus, methods of training and evaluation requires continuous consideration. Research should be undertaken to determine the effectiveness of a sample of the current programmes and to develop performance standards. The possibility of LOFT exercises for flight attendants could also be considered. JAR OPS will require flight attendants to carry out CRM training. Additionally, on promotion to senior status, flight attendants will be required to complete safety promotion training which will include an additional CRM element.

4.3.6. Technical Training

Consideration should be given to the requirement for basic technical training for aircraft operations for flight attendants since recent accidents e.g. Denver, clearly illustrated the potential importance of this training. JAR OPS will require this aspect to be included in flight attendant training.

5. PASSENGER BEHAVIOUR

5.1. Presentation of Safety Information

In 1989 an investigation was sponsored by the CAA to determine the most effective ways in which passengers could be encouraged to pay more attention to safety procedures (ref 11). Passengers' opinions of the effectiveness of possible alternative introductions to the safety briefing indicated that an approach in which passengers are informed of the importance of their knowing how to carry out safety procedures would be more likely to encourage attention to the safety briefing and the safety card. The flight attendants were perceived to be primarily responsible for passenger safety in an emergency, suggesting that the lack of attention to safety information on the part of some passengers may be attributable to a belief that they need not assume responsibility for their own safety.

Almost 80% of passengers involved in the survey thought that the operators should encourage passengers to be more safety conscious. The passengers

suggested ways in which this could be achieved and these included tighter control over the stowage and quantity of cabin baggage, the restriction of smoking, alcohol and duty free goods, making safety briefings more interesting or varied and the promotion of safety education.

A second programme was conducted in order to investigate passenger comprehension of airline safety information. Two experimental studies were conducted in order to investigate:

(a) The effectiveness of safety cards for conveying safety information to passengers; and

(b) The effect of varying the content of information presented in safety briefings on passenger attention.

In both the experimental studies, volunteers boarded a stationary aircraft and were given a safety briefing. An emergency situation was simulated and the volunteers were instructed to put on their lifejackets, and then to brace for an emergency landing.

Volunteers' knowledge of the less complicated safety briefing card information, such as the location of the oxygen masks and when and how to inflate the lifejacket, was generally high. However, volunteers' knowledge of more complex procedures, such as the correct method of donning the lifejacket and of operating the overwing and main exits, was more limited. A comparison of lifejacket donning times indicated that volunteers who donned their lifejacket four hours after having seen a standard safety briefing were not significantly slower than those who donned the jackets 5-10 minutes after the briefing. Volunteers' opinions indicated that emphasis on the importance of passengers knowing how to operate items of safety equipment in briefings would not discourage the majority of them from flying and would be likely to increase attention to safety briefings.

A number of human factors problems were identified as affecting volunteers' ability to carry out safety procedures quickly and effectively. For example, the lack of specific information (in all of the briefings investigated) led to problems in locating and retrieving the lifejacket from under the seat. Inadequate instructions led to the loss of valuable time as passengers tried to find out how to open the lifejacket container and identify the inside and outside of the jacket. These problems indicated the need for more specific information to be included in the safety briefing and on the card to ensure that the correct method of operating safety equipment and the appropriate procedures to adopt are obvious to passengers.

Although air travel was considered by passengers to be the safest form of transport, aircraft accidents were perceived to be less survivable than accidents involving other forms of transport. Previous findings that passengers tend to underestimate their chances of survival in aircraft accidents were supported by passengers' relatively low perceptions of their survival chances in eight different aircraft emergency situations.

5.2. Passenger Training

In 1994 a project involving members of the public was undertaken to determine whether practising emergency safety procedures in a non-threatening environment improved performance in a simulated emergency. The project also provided information on whether training improved passengers' knowledge of airline safety procedures. In this study one group of participants were trained in a 737 aircraft simulator in emergency procedures. A "control" group received no training and were used as a comparison group to enable the effect of training to be evaluated. The effect of training and the performance of the "control" group was evaluated during a simulated emergency on a Trident Three aircraft. The results indicated that a training programme incorporating instruction and practice in the use of certain cabin safety procedures and equipment, enhanced performance of those tasks in a simulated emergency. The improvement was particularly noticeable for procedures which were novel or complex e.g. locating the lifejacket, adopting the brace position. An increase in safety information following participation in the training was demonstrated by all participants (ref 11). There are however many potential problems associated with the introduction of passenger training centres. These include different location and operation of lifejackets and oxygen, different international standards for the brace position, different aircraft specific equipment such as door/exit operation, slides etc. Also who provides the resources, who pays and who trains?

5.3. Future Considerations

5.3.1. Aircraft Safety Information

An evaluation of alternate methods to assist members of the public to follow the emergency procedures accurately in an evacuation together with research into the potential benefits of alternate methods of training is required. The length and content of safety briefings/training should form part of the evaluation.

5.3.2. Cultural and Language Differences

One of the difficulties to overcome when safety information is required is to ensure that it is understood by passengers from many cultures and tongues. A project is currently being undertaken by the JAA Cabin Safety Working Group to explore the effectiveness of symbols for conveying information to passengers about the location of exits.

5.3.3. Survival Perception

The survey of passengers' perceptions of aircraft accident survivability indicated that a more realistic image of aircraft safety is required. The public need to be made aware that the majority of aircraft accidents are survivable and the information contained in safety briefings and on safety cards may save their lives (ref 11).

5.3.4. Passengers with Mobility Problems

The research which has been undertaken has been based on the ability of adults with no physical or mental difficulties to follow the emergency procedures. Consideration should be given to the factors which could influence the survival of other groups of passengers in an emergency.

6. CONCLUSIONS

In the last decade major cabin safety research programmes have been undertaken which have provided important new information. As the airframe manufacturers continue to develop larger and more sophisticated cabins, the need to continue to improve the probability that all of the passengers and crew will survive in the event of an accident, will remain our primary goal.

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Cabin Safety Research at the Civil Aeromedical Institute
Goals for the Near Term

G.A. "Mac" McLean, Ph.D.

ABSTRACT

The Cabin Safety research program at CAMI has several components. All are related to survival in and after a transport airplane crash. Current and proposed near-term efforts include evaluations of operational parameters related to aircraft evacuations, determinations of the effects of cabin layout on the evacuation process, assessments of manufacturing test methodologies and visibility requirements for inflatable escape slides, and evaluations of possible enhancements to airline operations related to water landings and ditchings. Potential improvements in techniques for enhancing individual passenger survival in accidents are also being studied. The results of these efforts will be used to form the basis for rulemaking activities through: 1) direct input to the Aircraft Certification and Flight Standards Services, 2) support of the Aviation Rulemaking Advisory Committee and its Performance Standards Working Group, 3) input to FAA-sponsored standards development by SAE, and 4) consultations to the industry.

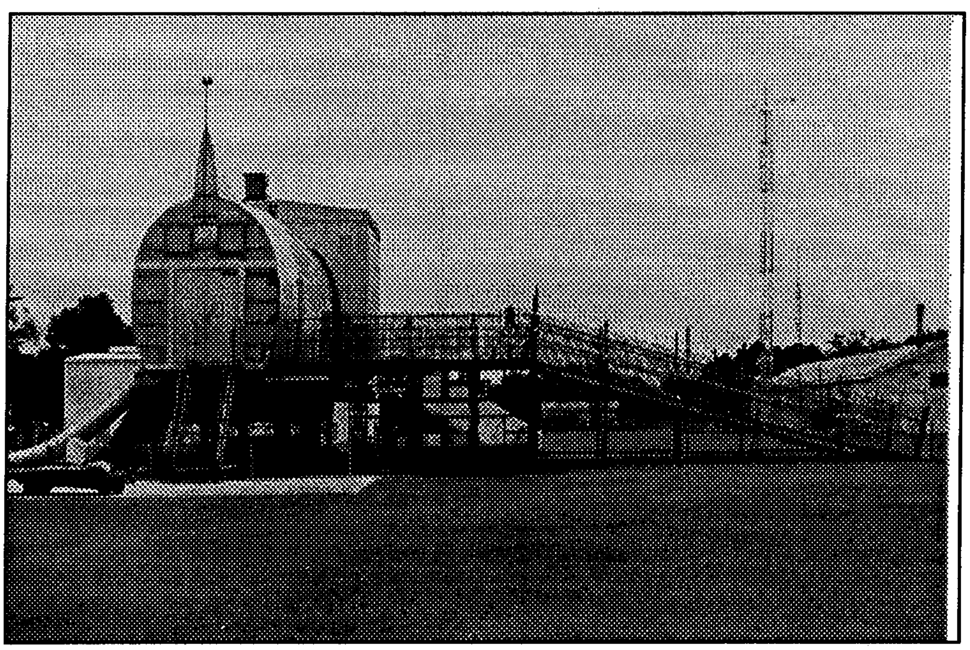
CAMI Cabin Safety Research Program Components

- Effects of configurational and operational variables on emergency evacuations
- Evaluation of water survival equipment and techniques
- Emergency equipment evaluation and testing
- Field research (as available)
- Grants / contracts (as necessary)

Research Facilities

- Narrow-body aircraft cabin evacuation facility
- B- 747 wide-body simulator
- Mobile aircraft cabin facility
- Water survival tank
- Aviation industry facilities

Narrow Body Evacuation Facility



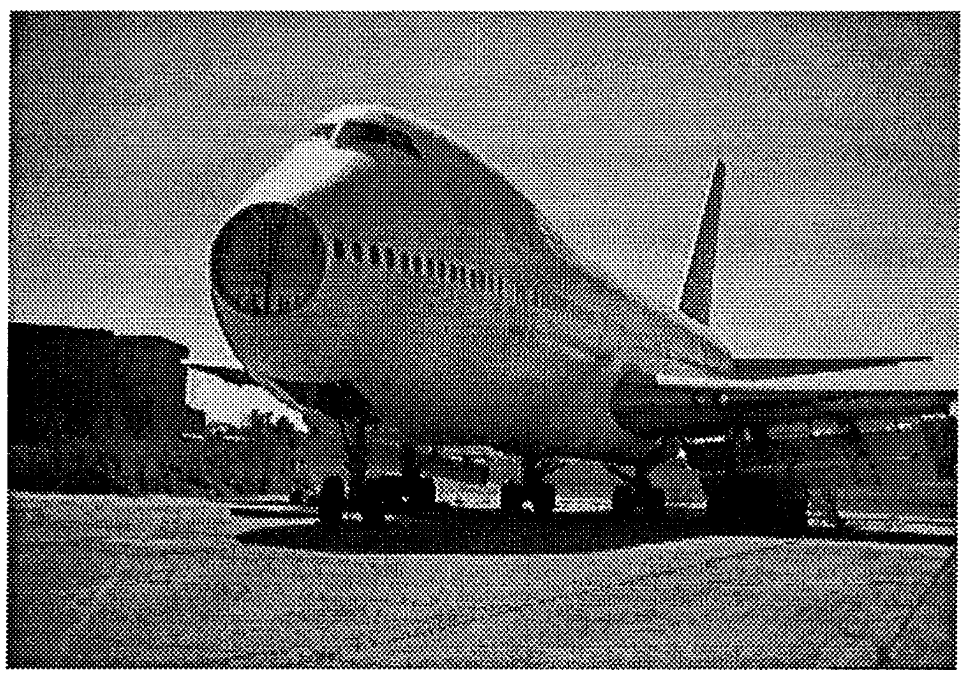
Recent narrow-body evacuation activities

- Effects of motivation and escape route on evacuations
- Effects of floor level exit height on evacuations

Near-term narrow-body evacuation facility activities

- Flight attendant location study
- Visibility of aircraft cabin objects in smoke

B-747 Wide-body Evacuation Simulator



Recent Wide-body simulator activities

- Modifications to wings / fuselage / control surfaces
- Modifications of girt attachments to accept different slides
- Development of escape slide strength test methods

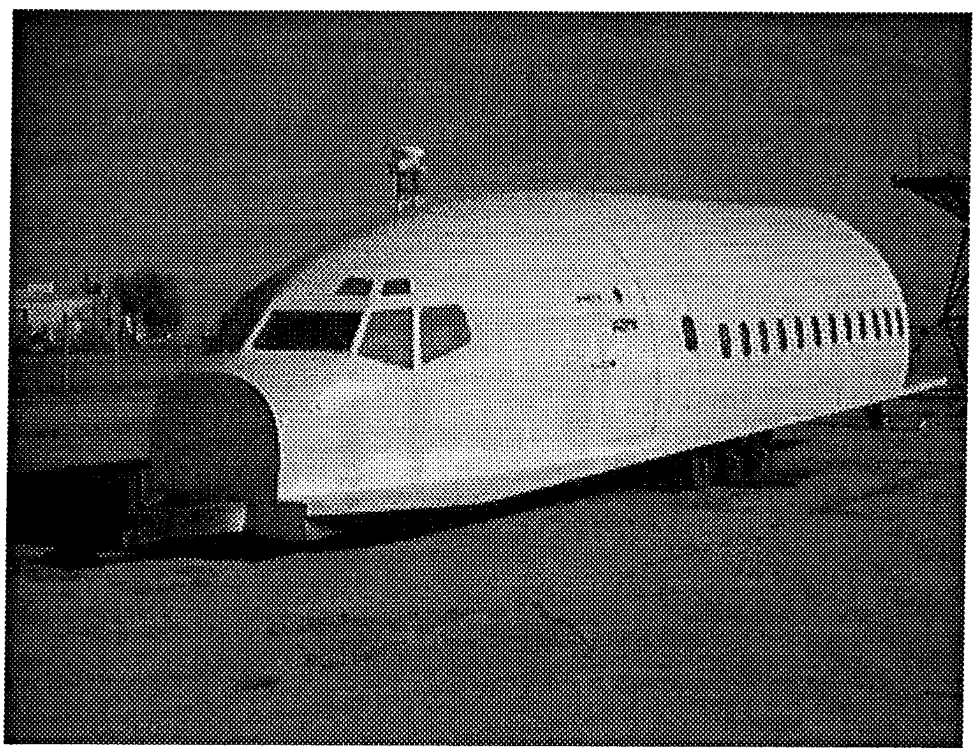
Wide-body Preparations to be Completed

- Positioning and permanent tie-down
- Installation of utilities (electrical, water, restrooms)
- Interior configural modification as required for studies

Near Term Wide-body Activities

- Study of escape slide strength test methods
- Study of cabin configuration effects on evacuations
- Gathering human performance data for modeling validations

Mobile Aircraft Cabin Facility



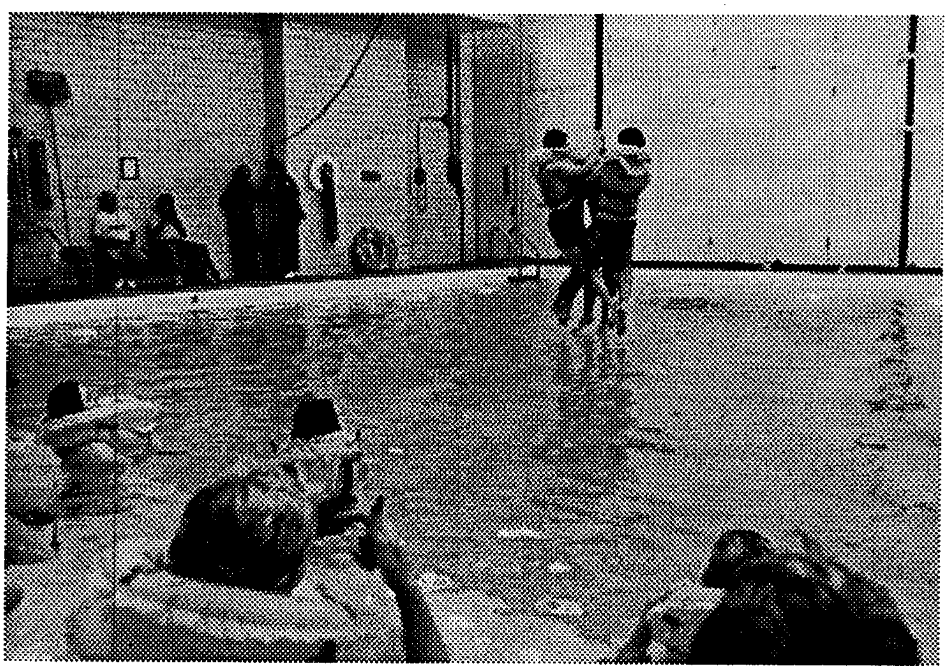
Preparations to be Completed

- Completion of interior and furnishings
- Installation of electrical power
- Fabrication of wing roots for use of Type-III exits

Near Term Mobile Aircraft Cabin Activities

- Study of overwater egress
- Survey of passenger knowledge on cabin safety topics
- Study of enhanced techniques for passenger survival

Water Survival Tank



Recent Water Survival Activities

- Fabrication of a child flotation test dummy (ATD)
- Collaborative development of the CAMI lifevest
- Study of the efficacy of infant flotation devices
- Study of techniques for flotation seat cushion use

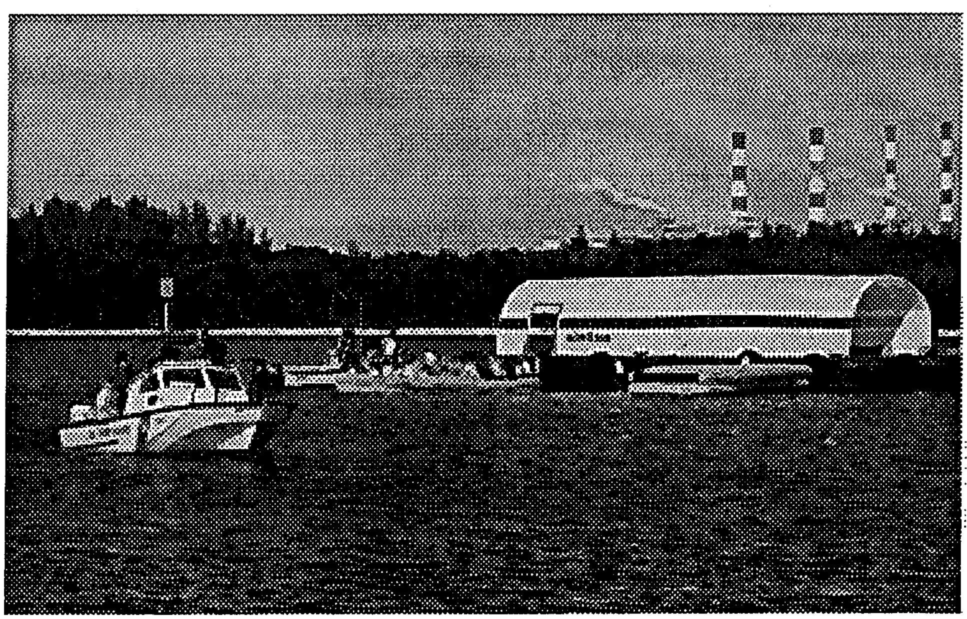
Near Term Water Survival Activities

- Study of child flotation using an adult lifevest
- Study of in-plane and in-water lifevest donning techniques

Recent Associated Research Activities

- Ditching / Water Survival disaster drill
- Grant research to study optimal cabin layout designs

Disaster drill off Ft. Lauderdale, Florida



Benefits from Disaster Drill Field Research Activities

- Evaluation of hands-on flight crew skills and knowledge
- Ability to evaluate actual search and rescue operations
- Enhancement of research staff perspectives on actual emergencies and emergency response activities
- Provide on-site support to activity participants

Grant Research

- Optimal Passenger Cabin Layout Design Using a Genetic Algorithm

Research Finding Applications

- direct input to the Aircraft Certification and Flight Standards Services
- support to the ARAC Performance Standards Working Group
- support of FAA-sponsored standards development by SAE
- provide Cabin Safety consultations to the aviation industry

Special Considerations for Cabin Safety Research

- Harmonization with other regulatory authority activities
- Collaboration with industry
- Protection of human subjects
- Adequate support and funding

A Flexible Cabin Simulator

by
Jeffrey H. Marcus
Manager, Protection and Survival Laboratory
Civil Aeromedical Institute
U. S. Federal Aviation Administration

ABSTRACT

Experimental research on issues related to emergency evacuation of a passenger aircraft cabin have tended to use existing aircraft cabins. While a great deal of useful information has been collected, these facilities have limited capabilities to be configured to investigate new or unusual cabin arrangements. A concept design for a flexible cabin simulator has been completed and is described. The proposed facility can simulate any aircraft cabin from a small, commuter category aircraft through a multi-aisle, multi-deck mega-jumbo transport. The simulator allows full flexibility in terms of exit type and placement, location and design of interior monuments, and the size and layout of the passenger cabin. Experimental control is possible of interior and exterior illumination levels, the presence of vision obscuring smoke, and the door sill height when using evacuation slides. Built from modular sections, it might be used in the future to investigate new and unusual cabin designs, such as the flying wing. The proposed simulator is described to illustrate its versatility. The associated building and project cost are also discussed.

INTRODUCTION

Experimental research concerned with emergency evacuation of a passenger aircraft frequently uses aircraft cabin simulators. People serving as research subjects are placed in these simulators, which are configured to represent a typical airline passenger cabin, and then asked to evacuate as quickly as possible. Some aspect of cabin design or operational procedures, such as the width of aisles leading to exits, is then varied. Interactions between experimental subjects, their time and behavior while evacuating, and the cabin design are studied with the goal of evacuating the cabin in as short a time as possible.

Current cabin simulators are either retired aircraft, or a special purpose simulator that faithfully duplicates a single, or limited number of aircraft. The use of such simulators places many restrictions on the ability to conduct research. With these types of simulators, the location, size, and design of exits cannot be changed. New cabin designs, such as multi-deck, multi-aisle mega transports carrying 700-1,000 passengers cannot be simulated, nor can radically different aircraft designs, such as the flying wing, be studied. Consideration is currently being given to such aircraft designs that will present new unanswered questions related to emergency passenger evacuation. Finally, current simulators are not generally located adjacent to a water tank or swimming pool. This precludes the study of issues related to evacuation from an aircraft into water.

Regulatory issues related to emergency evacuation are a continuing concern. In many cases. decisions must be made for which there is little or no scientific research on which to base the decision. Frequently, the lack of research is due to lack of appropriate facilities for conducting the research. For example:

1) The requirement for a maximum of 60 feet between exits. The safety of a greater spacing could not be shown experimentally because no facility exists for varying the distance between exits.

2) The use of exits of a different size or design from those specified in airworthiness regulations is difficult. Determining appropriate ratings, and allowing their use is difficult.

3) The use of evacuation slides with multi-deck aircraft presents a number of new issues. Will there be slides from each deck, or will passengers need to make their way to a main deck before leaving in an emergency? If each deck has a set of slides, will people exiting from a slide from one deck interfere with people exiting from an adjacent slide connected to a different deck?

4) Limited ability of current evacuation research facilities to reconfigure their arrangements has hampered development of parameter data sets and validation exercises for computerized evacuation models. For the same reason, there has been only limited study of analytical techniques to address certification issues related to evacuation.

This document describes the requirements of an aircraft cabin simulator flexible enough to be reconfigured to study whatever evacuation issue needs to be examined. The requirements of the simulator, as well as required support facilities, is described. Projected construction costs of both the simulator and associated building are summarized. Finally, the current status of a Federal Aviation Administration (FAA) project to construct a flexible cabin simulator is discussed.

REQUIREMENTS OF A FLEXIBLE SIMULATOR

The most fundamental requirement of a flexible simulator is the ability to simulate any type of a passenger aircraft cabin, from a small, "commuter" category aircraft through a large multi-deck, multi-aisle jumbo transport. The jumbo transport is limited to a maximum of three aisles and three decks, with 3-5-5-3 seating. Within these constraints, any width and/or length of a passenger cabin can be simulated. A crew of two to four technicians and investigators working four to six weeks will be able to disassemble a configured cabin, and erect a different cabin.

The exterior appearance of the cabin is not important, but the interior appearance resembles a current commercial airliner. Within the cabin, it will be possible to locate any size and/or design of an aircraft exit anywhere along the length of the cabin. Exits can be located and used from either or both sides of the cabin. Interior monuments and bulkheads of varying size and shape can be installed anywhere within the cabin. Seat pitch is adjustable.

Evacuation slides are an important part of the emergency escape system. As such, the simulator must be able to use any current (or future) design of an aircraft slide. This requires that the door sill height be adjustable within the range of current aircraft. An open area at the end of each slide must be available so that research subjects using the slide can tumble at the end of the slide without hitting anything (e.g., a building wall).

Both cabin interior and cabin exterior illumination levels are variable to control for the influence of lighting levels on evacuation. A non-toxic theatrical smoke can be introduced into the cabin. This smoke completely obscures vision to simulate the visual impairment of smoke from an aircraft fire. After a smoke filled cabin evacuation is conducted, the air in the simulated cabin can be quickly exchanged with clean air so that subsequent experimental runs can be conducted.

REQUIREMENTS FOR A BUILDING

Early concepts for the flexible simulator envisioned a series of modules that would be built up to represent the cabin configuration of interest. It was determined that such a system could not be practically built if it would be outdoors and required to be weatherproof. In addition to the need to weatherproof the simulators, there are other requirements for the facility that dictate the need for the facility to be enclosed. Among these requirements is the ability to schedule and conduct experiments without regard to weather or time of day. Current research facilities that may be located outdoors cannot be practically used to investigate issues related to cabin exterior illumination levels. Evacuation experiments require months of preparation, and coordination with hundreds of people. Everything must be ready at the same time in order to run an experiment. When research facilities are located outdoors, weather conditions at the time of the test may make conduct of the test unsafe. If a cabin side pool is available for water survival studies, use of this pool also requires that it be in an enclosed building. Thus, the ability to design, schedule and conduct experiments with full control of illumination and environmental conditions requires that a flexible simulator be enclosed in a building.

In addition to a large area to house the simulator, with an appropriately sized open area around the simulator for research subjects to tumble without striking the building when exiting a slide, the building is required to house laboratory and workshop space to devise and maintain experimental equipment. Among this experimental equipment are the modules and fixtures required to configure the simulator. The largest size cabin for which the simulator may be configured is the triple aisle, triple deck transport. Experiments with this cabin configuration require as many as 500 research subjects. All of these subjects need to attend a safety briefing and provide informed consent to participation in the experiment. Basic subject information, such as height, weight, gender, and age must be collected and recorded. Subjects are interviewed about health problems that may make them unsuitable for an experiment. To ethically conduct such health reviews, a semi-private area is required where a subject may be interviewed by a research investigator. When many people gather in a single location, requirements for bathroom facilities and parking for their automobiles become important considerations.

The simulator requirement for a cabin side pool to investigate evacuation into water imposes a number of requirements on the building. The pool must be wide enough to properly deploy aircraft slide/rafts, and it must be long enough so that a plane load of people can be in the water without being so crowded that collisions are likely between subjects in the water and subjects jumping from the cabin. The pool must be deep enough and wide enough so that subjects will not hit the sides or bottom of the pool. The requirement for evacuation from either or both sides of the simulator implies that either the pool must be movable, the simulator must be movable, or that suitable covers for the pool are available. Research subjects participating in water survival studies need an area to change clothes and securely store their personal belongings. Thus, locker room facilities are needed for as many as 250 of each gender.

CONCEPT DESIGN STUDY

Allen Consulting, Inc. (ACI) was commissioned by the FAA to perform a concept design study of a flexible cabin simulator facility[1]. The resulting study provided guidance as to the feasibility and cost of a flexible simulator and building. The requirements described earlier guided the design. Because of the wide variation in cabin width, two simulators are proposed. One can be configured for any cabin, from a small commuter category plane, to as large as a single aisle airliner with 3-3 seating. This simulator is restricted to a

[1] *Design Concept Prepared for the FAA Flexible Aircraft Cabin Simulator*, FAA Contract DTFA-02-94-D94303, August 1, 1995

single deck. The second simulator can be configured for a multi-deck cabin, with as many as three aisles. Both simulators are in a building with a water pool in between them. Covers can be placed over the pool when evacuations from both sides of a cabin onto dry land are being studied. Both simulators are on hydraulic positioning systems that can lift and tilt the simulators to any desired sill height and angle.

A series of artist concept drawings illustrating the flexibility of the simulator are shown in Figures 1-4. In these figures the dark area to the viewer's right of the cabin is the water pool. The simulator is shown in the rest position (i.e., door at floor level) with evacuation slides mounted on the rear floor level exit. Figures 1 and 2 show the commuter and narrow body simulator configurations, while Figures 3 and 4 illustrate the wide body, and the triple aisle, triple deck mega jumbo transport configuration. Figures 5-8 illustrate seating plans for the commuter category, narrow body single aisle, wide body main deck dual aisle, and mega jumbo transport triple aisle main deck cabin configurations.

The flexible simulator uses a modular design. Simulated cabins are created by matching a number of modules representing a short section of a cabin. This module, in turn, is built from a number of components representing such items as floors, ceiling, exits, and walls. Use of the modular design maximizes the flexibility of different cabin arrangements and designs possible. Use of a modular design allows, at some future date, the rapid fabrication of new cabin design features, and the easy incorporation of new cabin design features at some point 15-20 years after the simulator is completed. Because only the module needs to be fabricated, these new features can be studied for minimum expense. Future modules may be as simple as different exit size or orientation, through new and different door operations, as well as the study of radically different designs of cabins such as those being considered for a flying wing.

Figures 9-11 illustrate this modular design. Figure 9 shows an exploded view of the modules that might be used to configure a commuter/narrow body cabin.. Figure 10 shows the same view for a triple deck mega-wide body cabin. Figure 11 shows an exploded view of a single module illustrating the components used to build a module.

The resulting building needed for such a facility is shown in Figures 12-14. Figure 12 shows a plan view of the building. Note the two simulators located adjacent to the evacuation pool. A bridge crane above this area allows the movement of pool covers from the storage area (shown on the left of Figure 12). The lobby of the building, shown on the lower right corner of Figure 12, can be transformed into a subject briefing area when large experiments are being conducted. Figure 12 shows the lobby as it might be set up with tables and chairs for processing subjects through their safety briefing, and in providing informed consent. Figures 13 and 14 show two cross sectional elevation views through the building, illustrating the simulators up on their positioning system. Note the location of the pool in Figure 13. In Figure 14, the orientation area/lobby is shown. Note in Figure 14 the administrative space above the lobby. Also note on Figure 14 the viewing gallery on the third level. From this viewing gallery, research scientists will be able to view experiments in the simulator area. The same area also permits monitoring during an experiment by the medical and safety staff required when using human research subjects.

The facility envisioned in the concept design features approximately 36,000 square feet of space for the simulator area, including a water survival tank 45 feet wide by 80 feet long by 15 feet deep. The associated administrative area, including the subject briefing/lobby area, offices, locker rooms, and equipment maintenance areas is 14,000 square feet.

ESTIMATED FACILITY COST

As part of ACI's concept design study, detailed cost estimates were performed. The wide body simulator cost was estimated as $4 million, and the narrow body simulator cost was estimated as $1.8 million. The building required to house the simulators is estimated to cost $9.3 million, exclusive of land cost. The pool required for water survival studies adds $900,000 to the cost of the building. Thus, the total facility, including wide and narrow body simulators, the required building, and a water survival tank, is estimated to cost $16 million.

SUMMARY

Aircraft cabin evacuation research relies on experiments conducted in retired transport aircraft, or in cabin simulators designed to represent one, or a limited number of aircraft. Current facilities significantly limit the ability of research scientists to design experiments. The locations, size, and shape of exits cannot be varied, nor can multi-deck or multi-aisle cabins be investigated. New, possibly radically different cabin designs, such as those associated with a flying wing, cannot be investigated. This paper describes the results of a concept design study to build a flexible simulator and its associated facilities.

The flexible simulator proposed features a number of unique and useful features. Any cabin size, width, and length could be simulated from a small "commuter" category aircraft cabin through a three aisle, three deck mega-jumbo transport seating 700-1,000 passengers. The simulator sits on a hydraulic positioning system, allowing door sill height to be adjusted. The simulator uses a modular design allowing for the rapid and inexpensive fabrication of cabin components, such as exits, essential to the study of future cabin safety issues. Interior and exterior illumination levels can be controlled, and a non-toxic, vision obscuring theatrical smoke can be introduced into the cabin. A cabin side pool allows the investigation of evacuation into water. The pool can be covered, allowing evacuation from both sides of the cabin.

The proposed simulator would be housed in a building permitting the scheduling and conduct of experiments without regard to the weather. The building is also required, because a weatherproof flexible simulator is not a practical design. The building has a large enough open area at the end of the evacuation slides so that research subjects can safely tumble without impacting building walls while exiting a slide. A large lobby, which can be reconfigured as a subject briefing room, is included in the building as are locker rooms for as many as 250 research subjects of each gender. The building's size is approximately 36,000 ft^2 in the simulator area, and 14,000 ft^2 of administrative space.

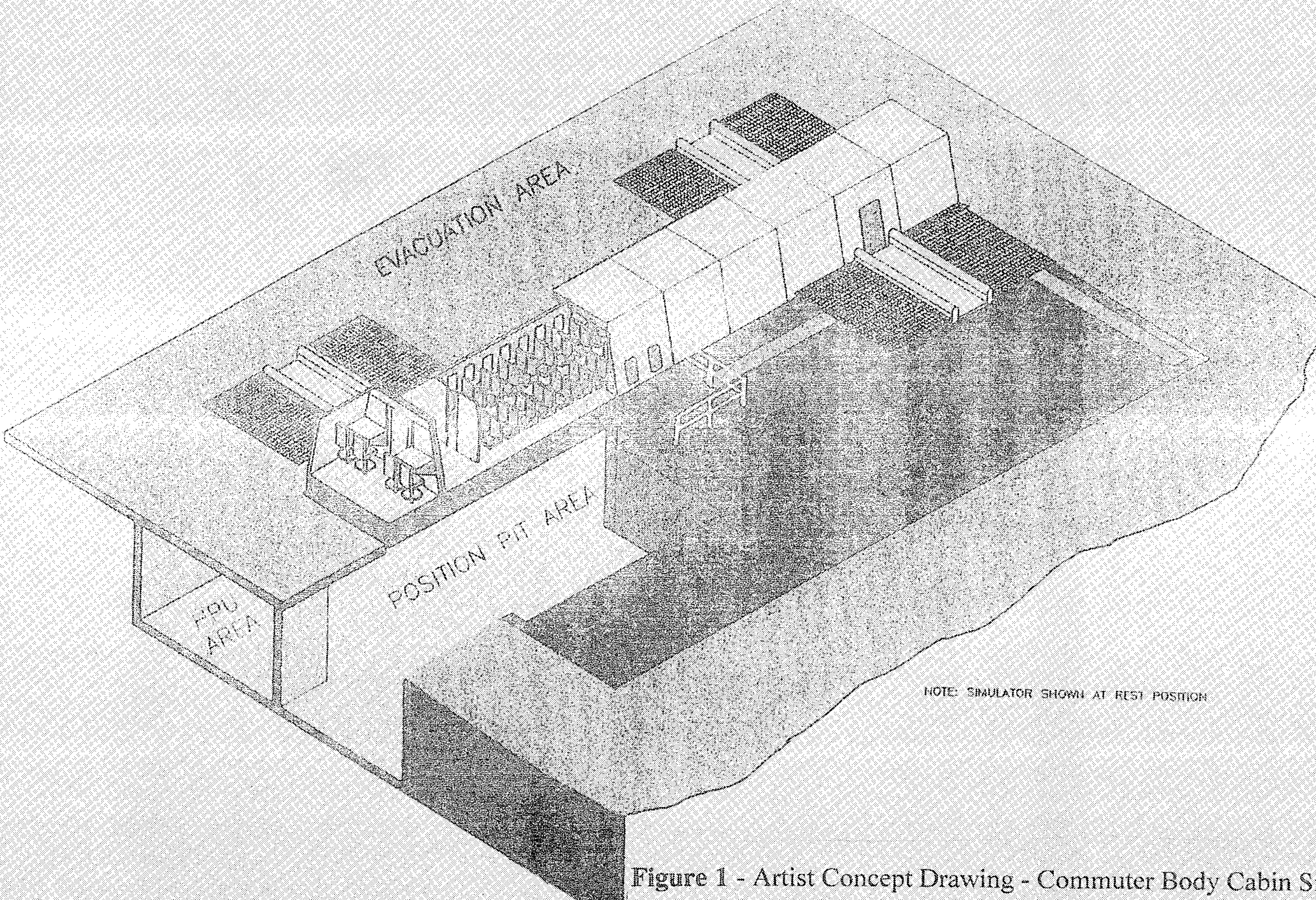


Figure 1 - Artist Concept Drawing - Commuter Body Cabin Simulator

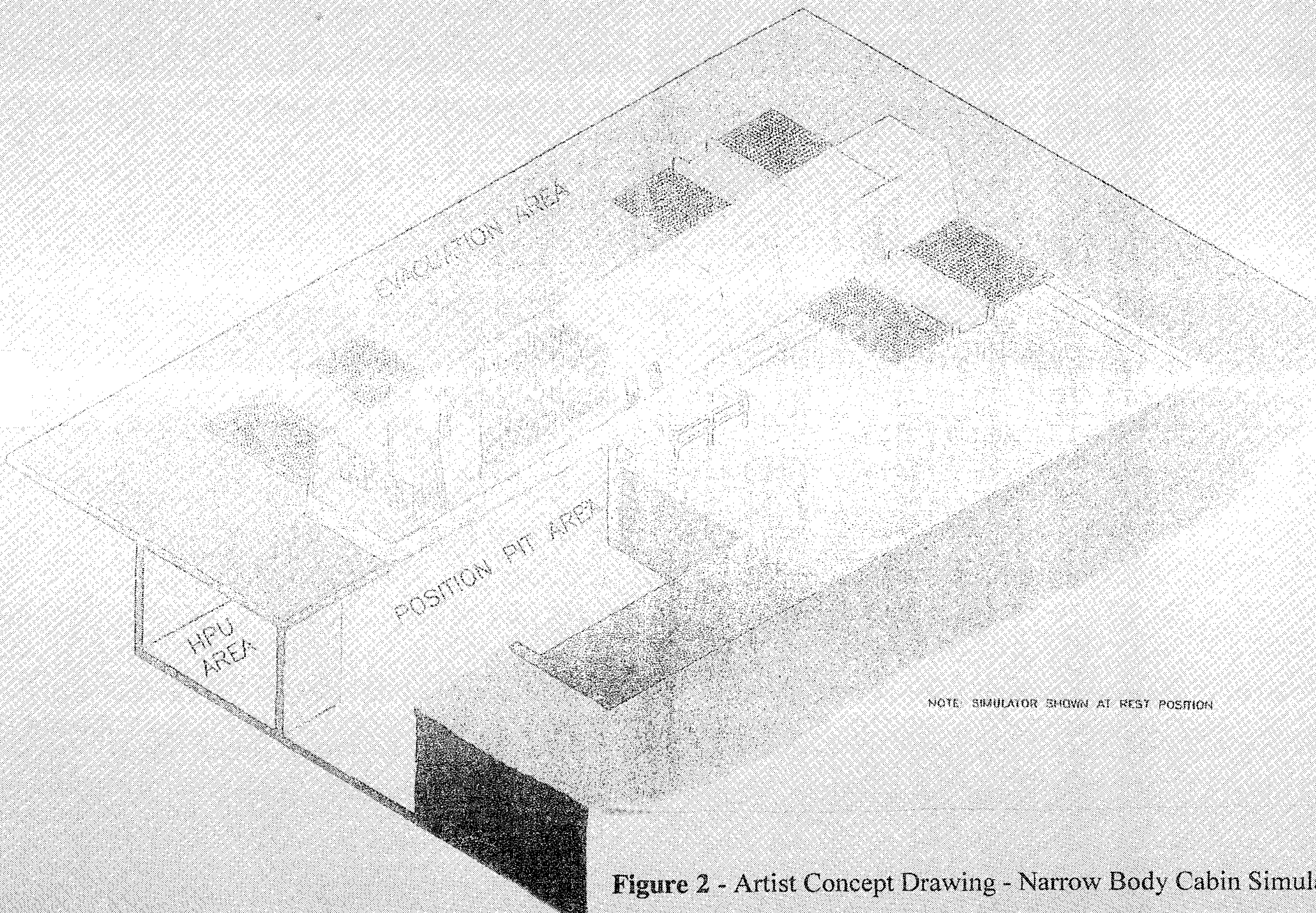


Figure 2 - Artist Concept Drawing - Narrow Body Cabin Simulator

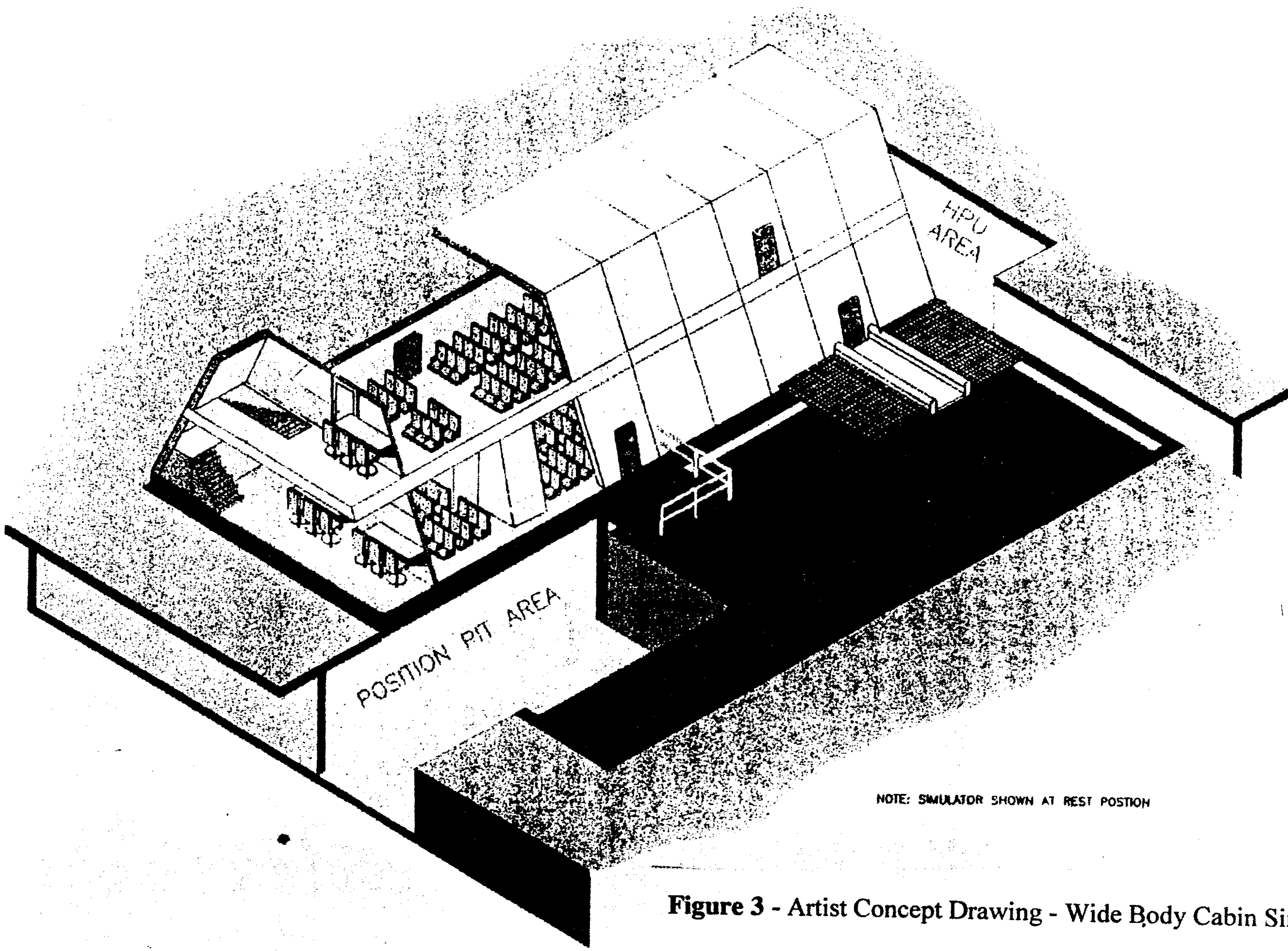


Figure 3 - Artist Concept Drawing - Wide Body Cabin Simulator

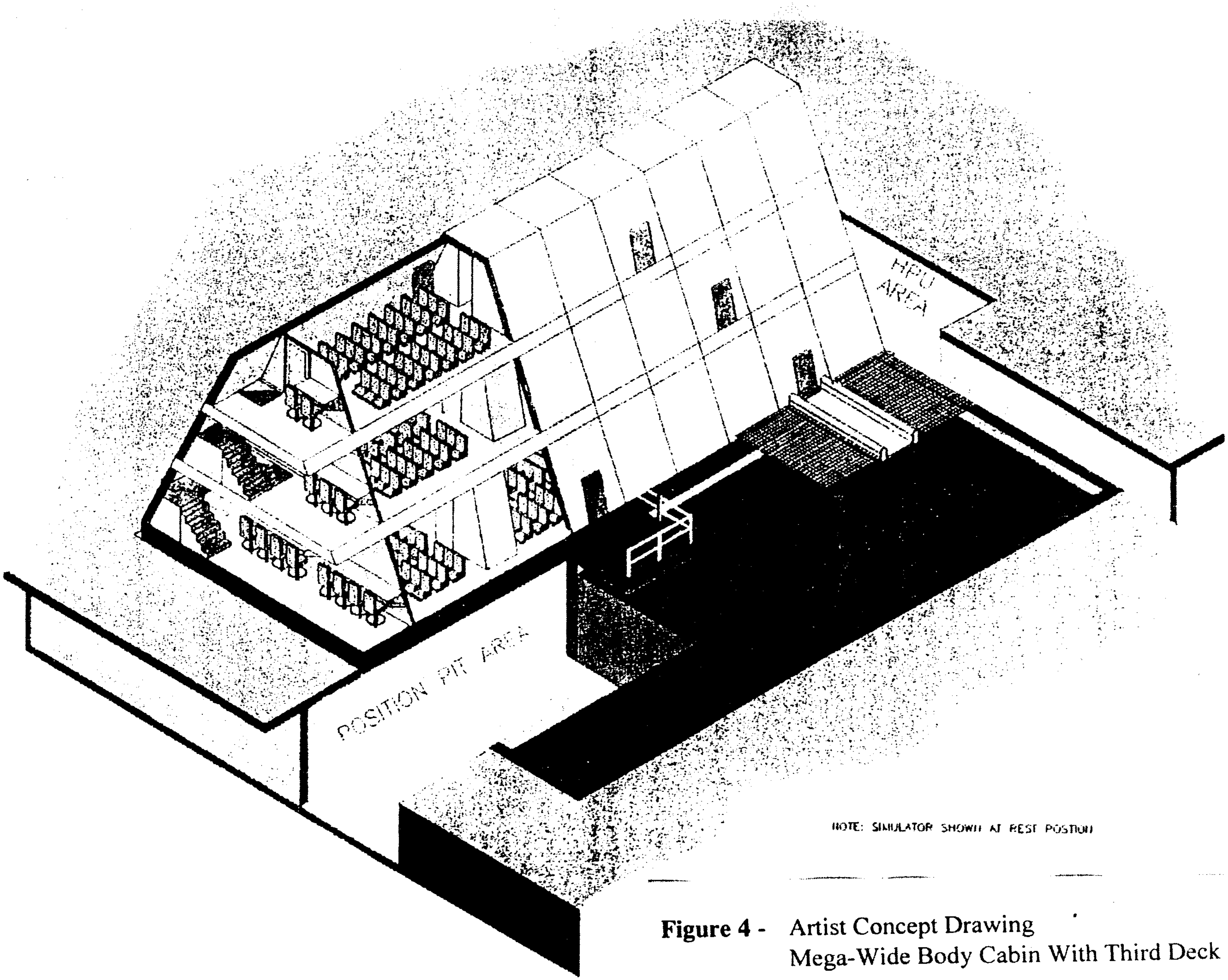


Figure 4 - Artist Concept Drawing
Mega-Wide Body Cabin With Third Deck

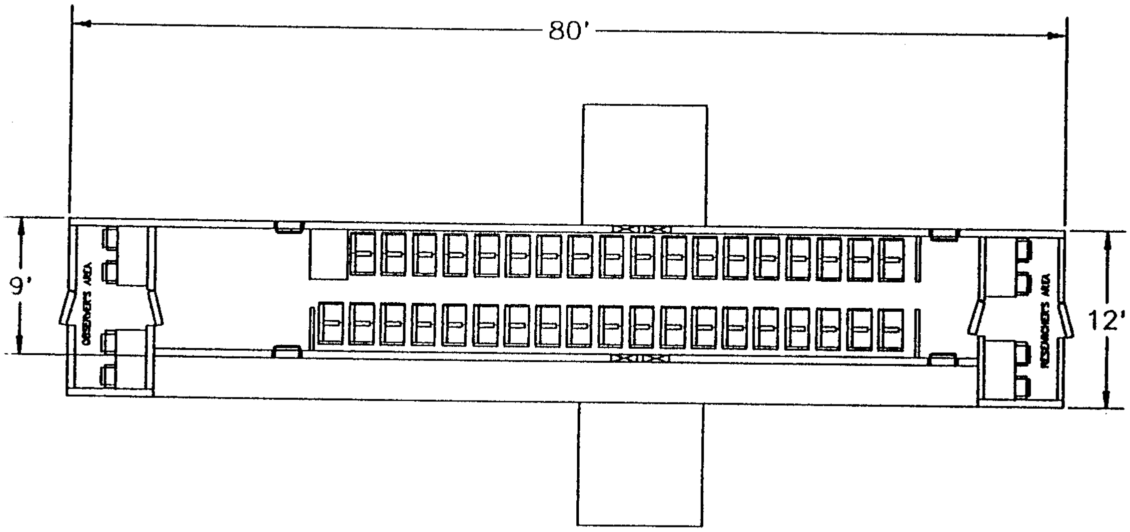


Figure 5 - Commuter Body Floor Plan

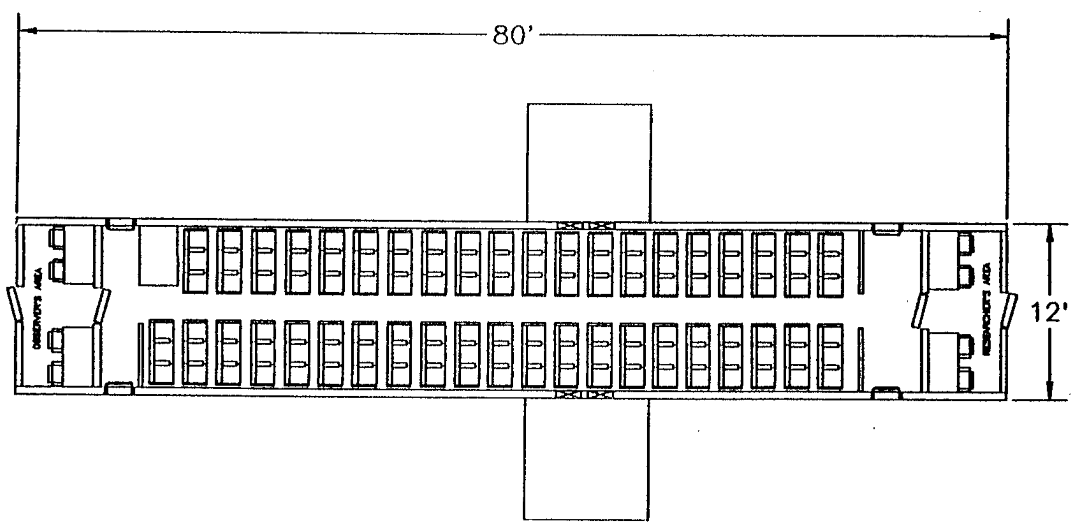


Figure 6 - Narrow Body Floor Plan

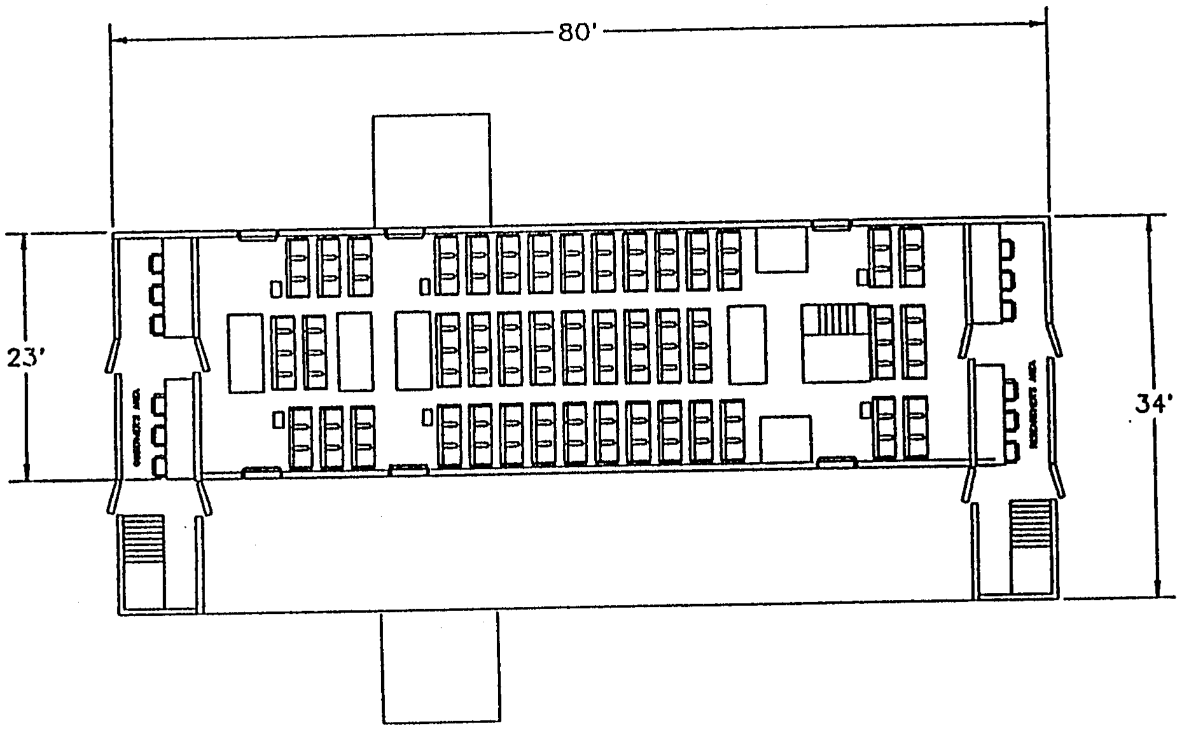


Figure 7 - Wide Body Main Deck Floor Plan

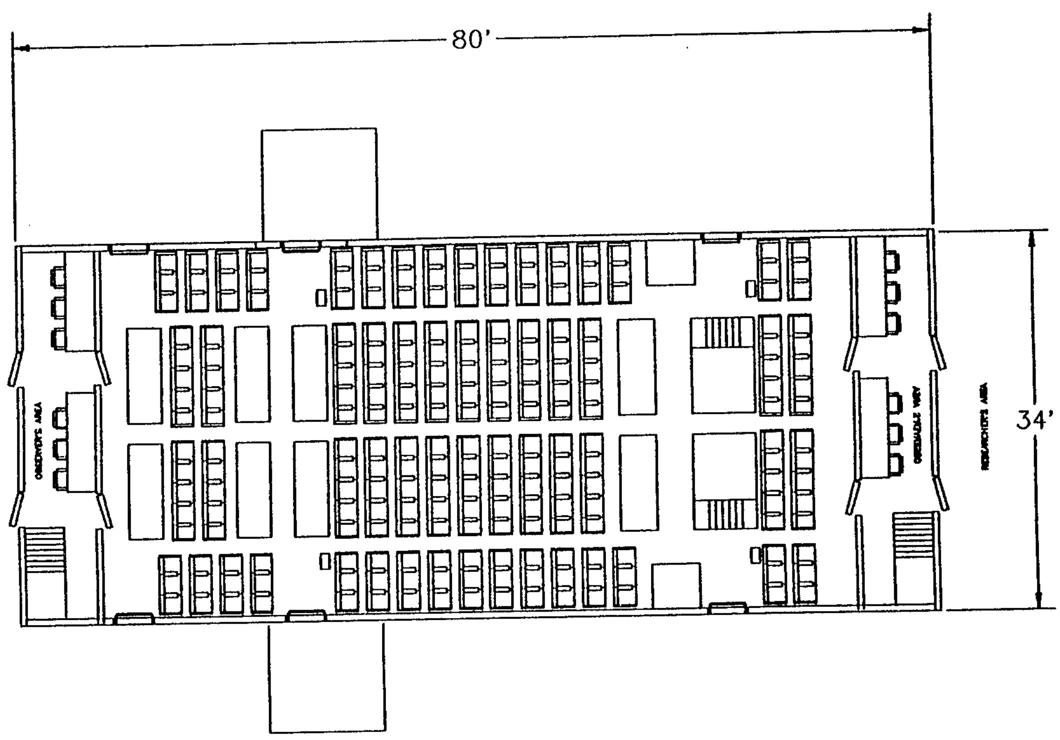


Figure 8 - Mega-Wide Body Main Deck Floor Plan

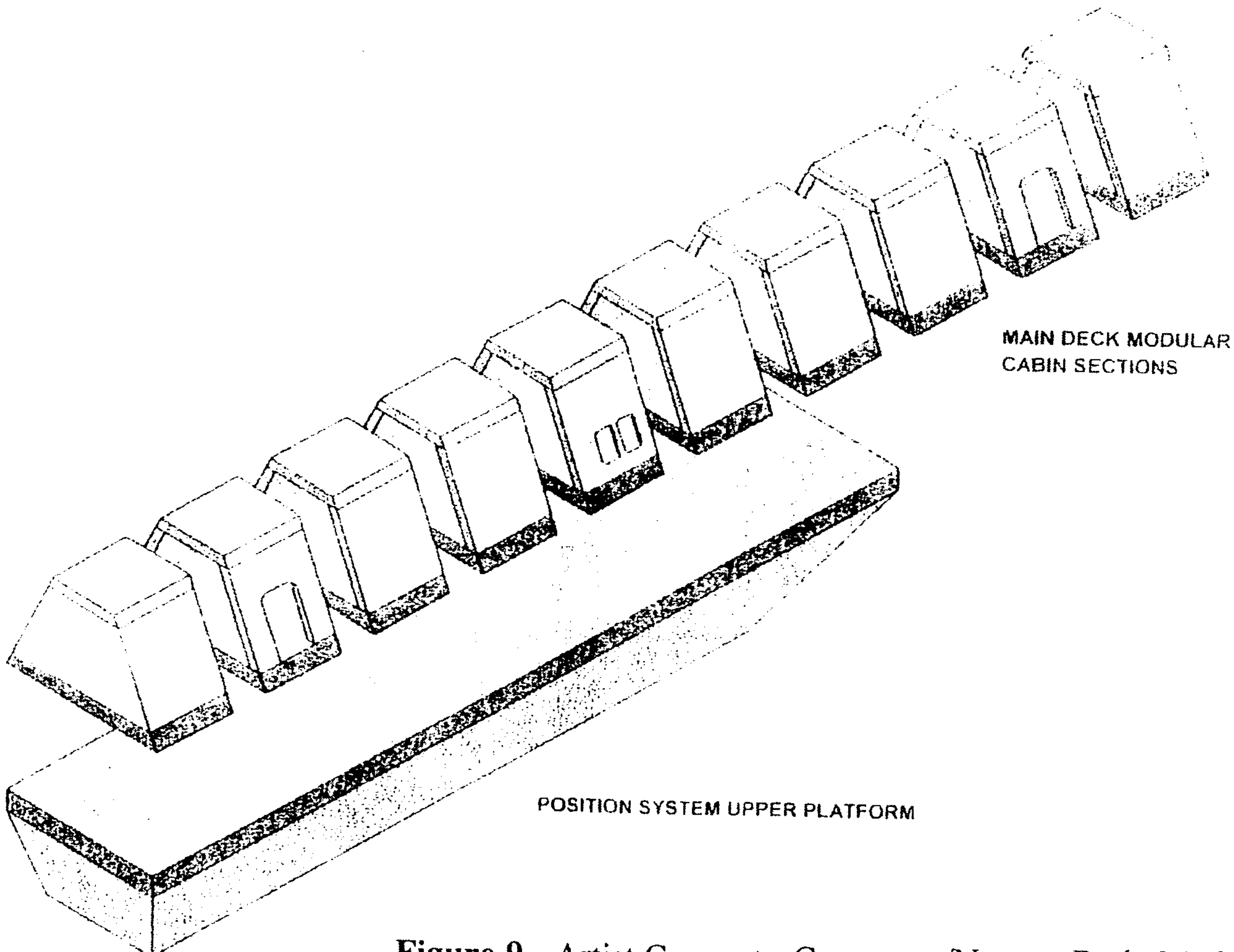


Figure 9 - Artist Concept - Commuter/Narrow Body Modules

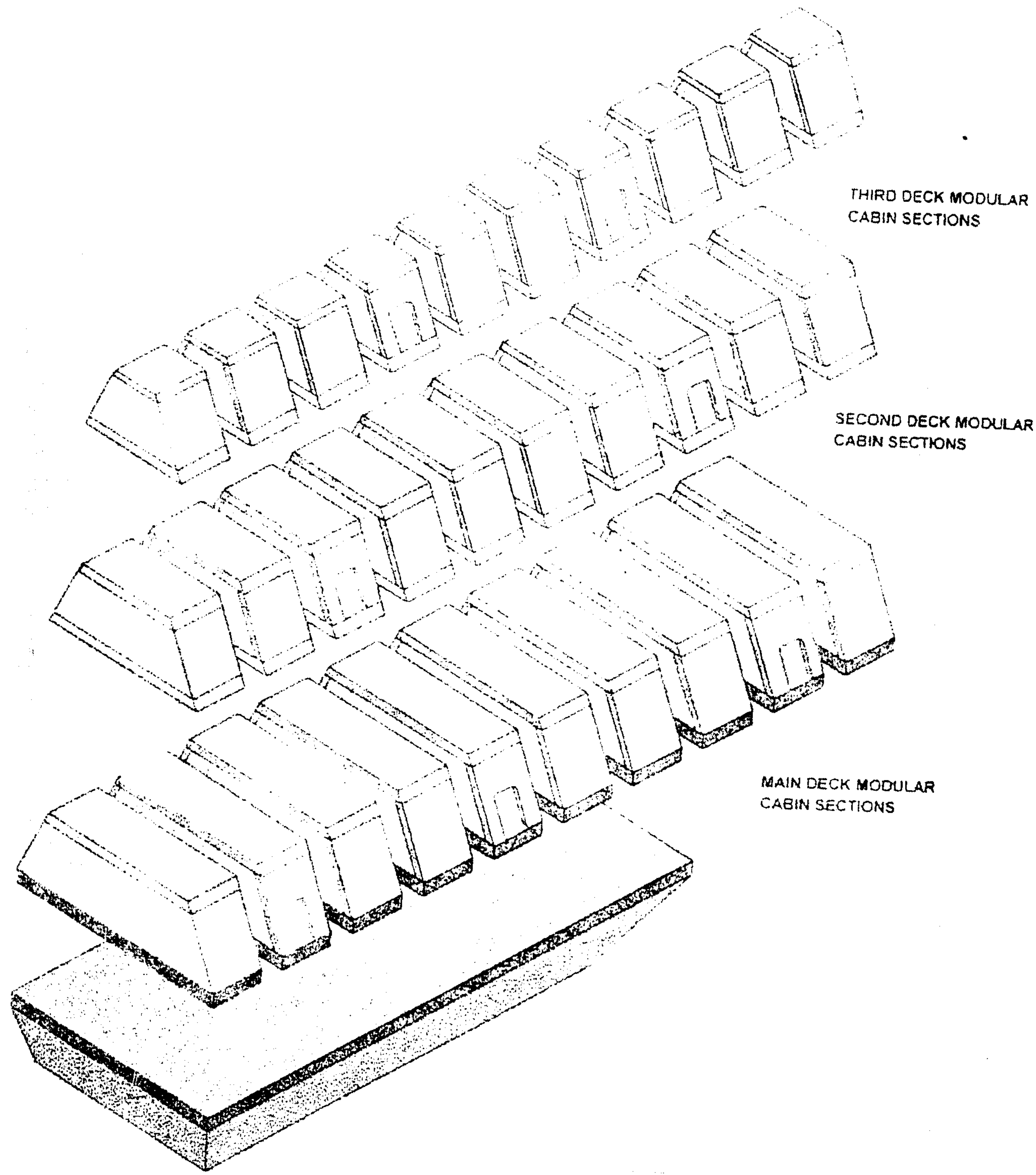


Figure 10 - Artist Concept - Wide/Mega-Wide Body Modules

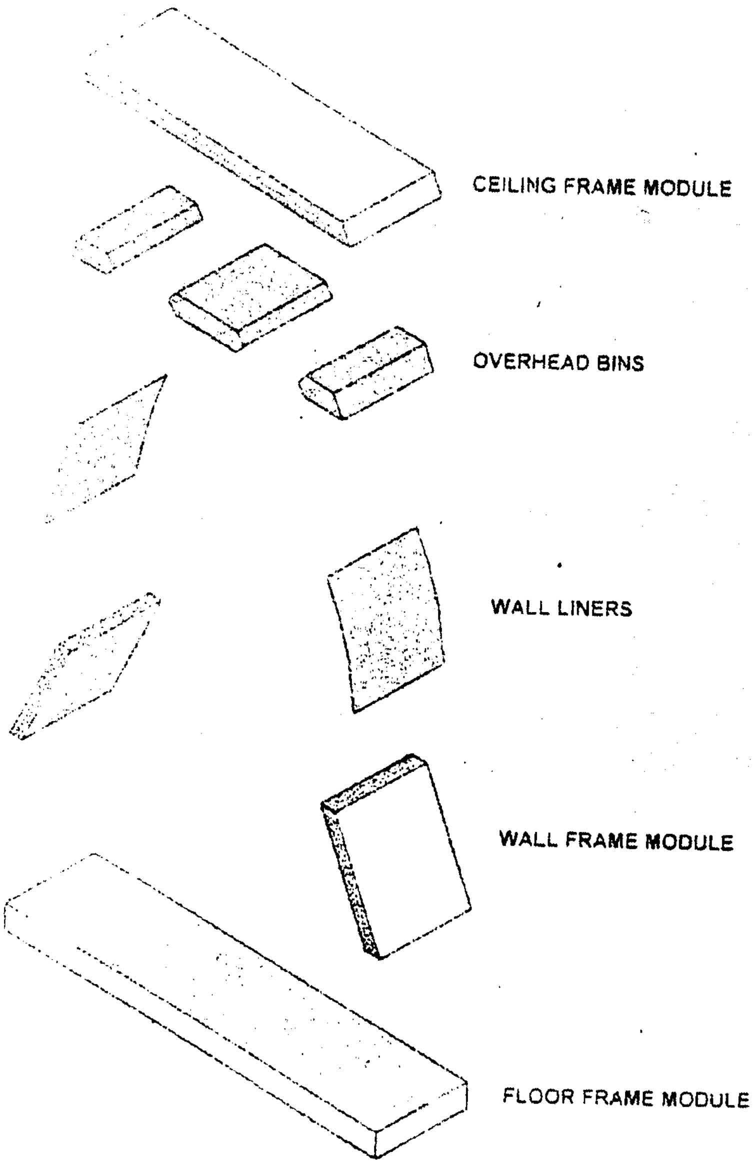


Figure 11 - Artist Concept - Exploded View of Typical Cabin Simulator Module

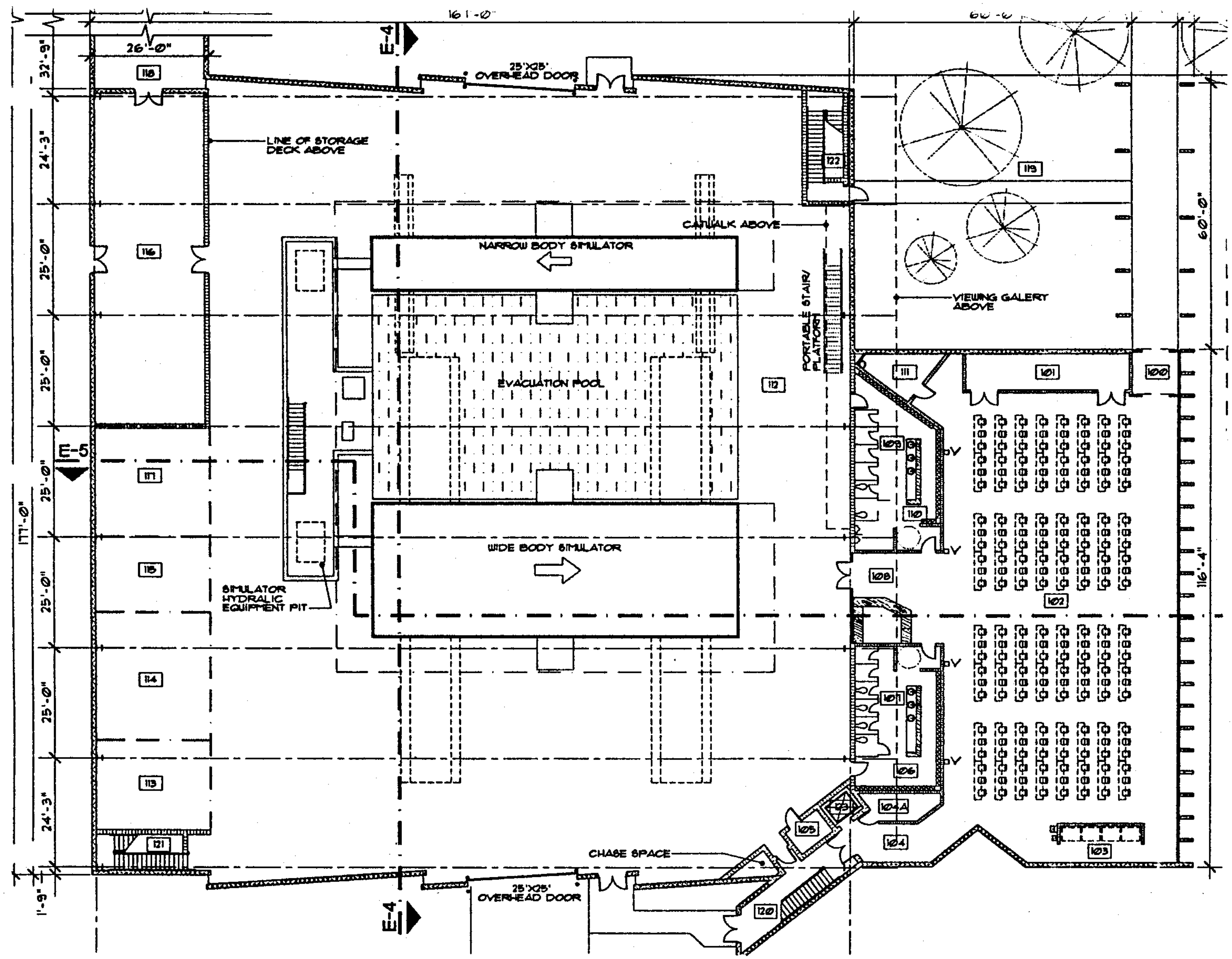


Figure 12 - Plan View of Proposed Facility

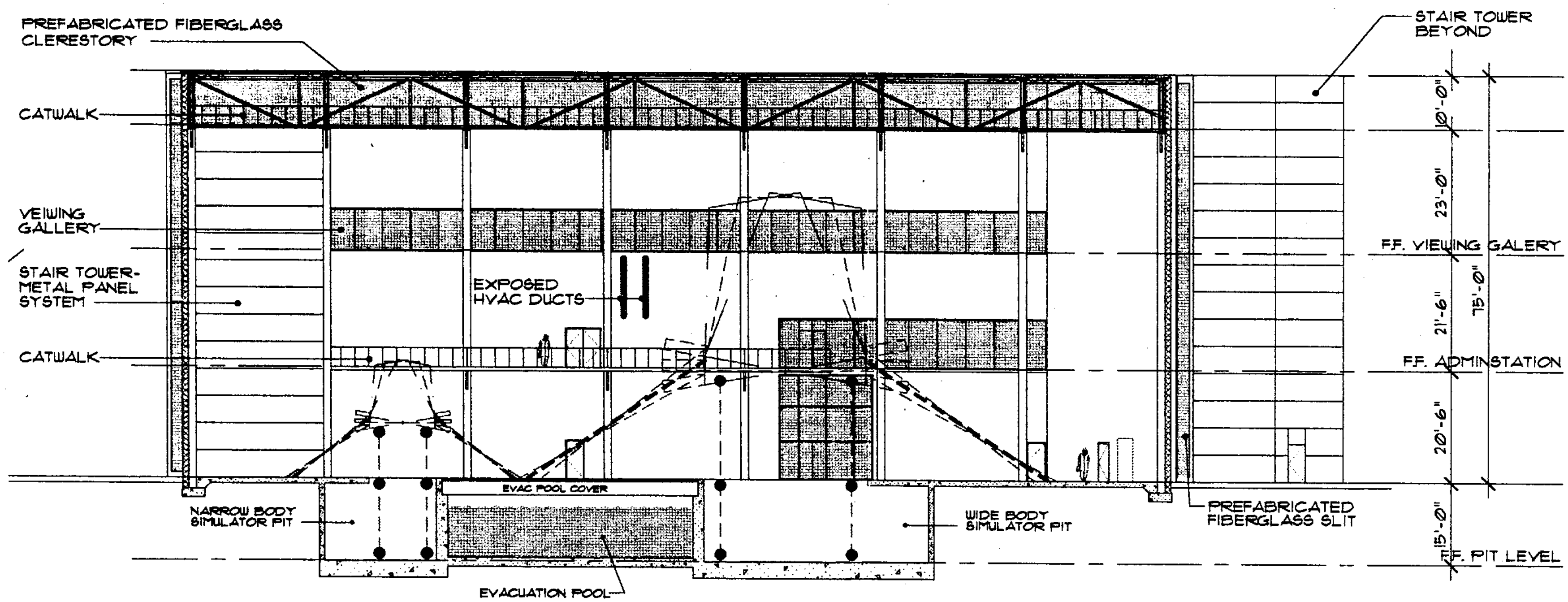


Figure 13 - Elevation View of Proposed Facility

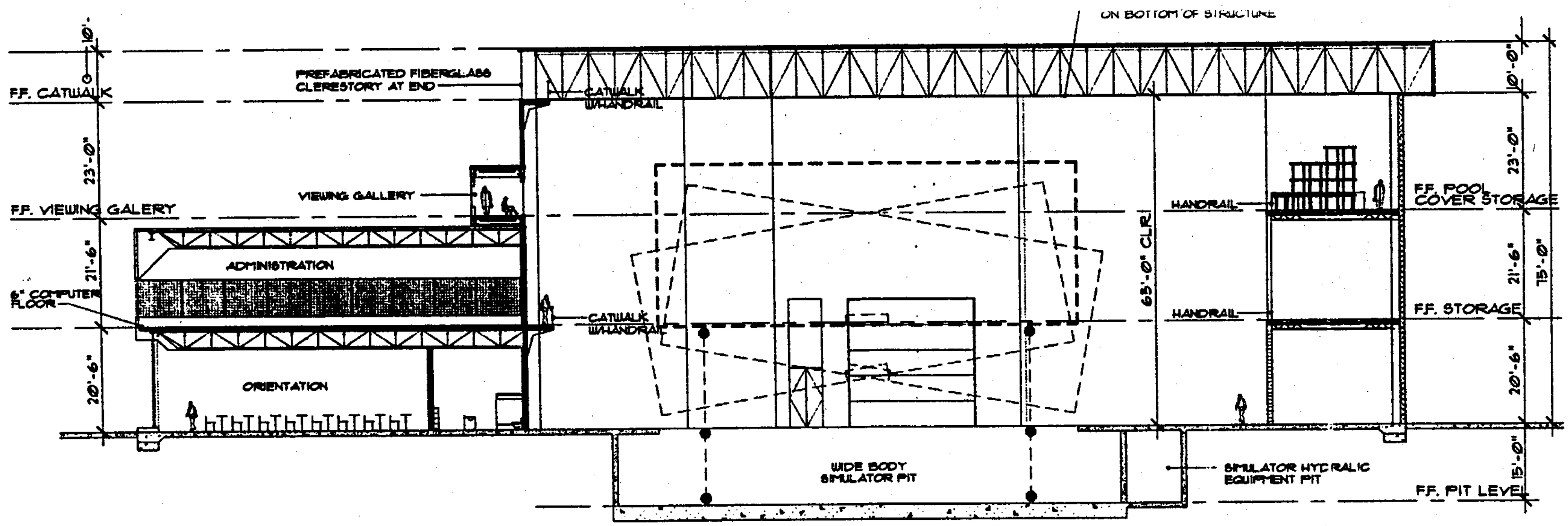


Figure 14 - Elevation View of Proposed Facility

INTERNATIONAL CONFERENCE ON CABIN SAFETY RESEARCH

EVACUATION COMPUTER MODELLING

by

K. Romi Singh

Aviation Research Corporation

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Harrah's Casino-Hotel
Atlantic City, NJ.

ABSTRACT

"Evacuation Computer Modeling"

K. Romi Singh
Aviation Research Corporation
Montreal, Canada

Computer modeling of complex stochastic phenomena such as evacuation processes, whether of aircraft or of any contained area, poses several challenges which begin in the pre-modeling stage and continue through to the post modeling stage of validation, calibration and use for decision making or gaining insight into the evacuation phenomena.

The normal process of modeling consists of the identification of the relevant input variables, their interactions, and the outputs with which to evaluate both the performance of the model and the impact of the inputs. Therefore, the usefulness of a model may be gauged in terms of the type of output and the reliability of the output in its predictive capability.

Passenger aircraft evacuation scenarios which are of interest in the present work fall into two broad classifications: certification and emergencies. The potential utility of a model depends on the degree to which each of these scenarios can be replicated in the pseudo-real world of the computer model, and the output reflect usable measures of performance of individual and collective human behavior.

This paper describes the challenges which have been successfully overcome by the modelers of aircraft passenger evacuation and those challenges which remain as yet to addressed. In particular, the focus will be on the difficulties of modeling human behavior and the steps which may be taken by the researchers, governing authorities and individuals in a position to observe or investigate actual evacuations, to advance the models and enhance the utility.

1. INTRODUCTION

The concern for the safety of occupants of closed quarters, such as transport systems, has occupied much of the efforts of the design teams over the centuries. Escape from burning buildings, oil rigs, sinking ships, collided cars, trains and busses all have been considered in the design and certification of public facilities.

There is continuing allocation of resources to the research and work on how to make the environment for the occupants of commercial aviation transport systems even safer . However, despite the best intentions and talents of the designers, regulators and the manufactures, we, as the community responsible for delivering such transportation systems, have been accused of overlooking some critical issues. Sometimes, we have not been able to completely address the issues, even though we were aware of them and depended on our best judgement to develop systems and procedures to resolve them.

To illustrate by example, in one case, we did not allow for the possibility of escape for our astronauts until we lost some in a catastrophic fight. Then we conjectured that we may have been able to save them had we had a different or additional design, set of priorities or procedures. In another case, we designed and flew one of the best wide body aircraft in the world. But, after experiencing and on board cabin fire, which posed minimal threat at the time, and landing safely, we allowed all occupants to be consumed by the fire and smoke in their seats although when the aircraft finished its landing roll, all occupants were alive and the fire was reportedly under control.

In both the examples, the vehicles were designed by the best in the world, the crews were trained for all sorts of emergency procedures, and were highly professional. However, both incidents served as cases from which additional insight into our shortcomings as designers, regulators, and operators were identified and new design, procedures and training were implemented.

As designers and manufacturers, we are constantly seeking ways to make profitable systems which meet the regulatory requirements and which keep us out of the courthouses. As regulators, we are also ever vigilant of the conditions under which we give our stamp of approval. As the public, we are constantly seeking transportation systems at a low price which have been somehow made as safe as possible by the combined efforts of the manufacturers and the regulatory agencies. There are obvious tradeoff required to achieve some balance between the objectives of each party.

In terms of evacuation from commercial aircraft, we have established criteria for certification. While these may or may not correlate with any measure of survivability of the occupants in the event of an actual evacuation, we have demonstrated , mostly through actual tests with volunteer participants, that these criteria can be met under the conditions set out by the regulatory agencies and have gone on to supply the certificated aircraft to the

marketplace.

As the aircraft have become bigger and higher off the ground, the demonstration of the fulfilment of the certification criteria has become both expensive, and dangerous for the participants. A number of injuries, some permanent, have been sustained by the volunteer participants in these tests. This has, of course, motivated us to look other ways of achieving the evaluation of the designs and procedures associated with aircraft cabins.

Almost without exception, we have turned to analytic techniques for certification although our confidence in these techniques remains less than complete, necessitating a continuation of real life tests, albeit with some concessions to prevent further injuries to participants.

We have, as early as the 1950's, used the latest and greatest tools to develop models which would allow us to gain insight into the passenger evacuation phenomena and develop measures of performance for particular designs and procedures. Of course, today the tools are far more sophisticated and the mathematical models to investigate the evacuation phenomena have the backbone of computers to perform the necessary computations in nanoseconds and provide results that appear to be impressive even if not completely verifiable and accepted by the regulatory agencies. Consider for example the animation of the ARCEVAC model.

In the research arena, we are now freely speaking of computer modelling as a potential tool for evacuation investigation and we have great expectations. It is the objective of this paper to place these expectations in a realistic framework of where we are in modelling and where we can expect to go with our computer models, given the necessary resources and set of priorities.

2. EXPECTATIONS

We have developed certain expectations of the computer models on the basis of not what we know about passenger evacuation modelling but possibly on the basis of our success with other applications of computer models in aviation. For example, the FAA has sponsored and virtually made a mandatory worldwide standard of its airport and airspace design model SIMMOD, which is used extensively for evaluating design and procedural decisions with respect to airport layouts and air traffic control.

Before comparing the environment in which these other models have application to the environment in which passenger evacuations are to be modelled, it is useful to enumerate a partial list of expectations we have formulated with respect to computer evacuation models. Specifically, we expect that we can benefit from computer modelling of evacuations in one or more of the following endeavours:

i) Certification of aircraft

ii) Aircraft Cabin Design

iii) Accident and Survivability Investigation

iv) Flight Crew Evacuation Training

In each of the above endeavours, we see advantages of being able to do on a computer what would otherwise have to be done with real life tests, which we know:

i) are potentially dangerous to participants

ii) are expensive

iii) cannot be conducted under truly hazardous conditions

iv) cannot be conducted on aircraft in the design stage

v) cannot accommodate certain types of passengers (eg. disabled and elderly)

vi) cannot replicate most types of aircraft emergencies

vii) provide only a limited sample of results

viii) cannot be conducted sequentially to improve aircraft design or evacuation procedures within reasonable limits of time, money and people resources

If we had a satisfactory computer model or set of models for the passenger evacuation phenomena, all of our expectations would be met and we could do all of the things we have said we cannot do in real life, which would, of course result in a superior product where the probability of overlooking some issue or de-prioritizing it would be minimised.

3. COMPUTER MODELLING

Computer modelling of complex, discrete event, stochastic phenomena such as evacuation processes, whether of aircraft or of any contained area, poses several challenges which begin in the pre-modelling stage and continue through to the post modelling stage of validation, calibration and use for decision making or gaining insight into the evacuation phenomena.

The normal process of modelling consists of the identification of the relevant input variables, their interactions, and the outputs with which to evaluate both the performance of the model and the impact of the inputs. Therefore, the usefulness of a model may be gauged in terms of the type of output and the reliability of the output in its predictive capability.

Not only do we need to identify the relevant variables, but we also need to define how they behave. This behaviour is established by some probability distribution, which is really a statement of how we have observed that variable's behaviour in the past or expect, in our judgement, for it to behave. In either case, we need some historical data or very good judgement.

Finally, in order to build the model, there has to be an awareness of the basic phenomena and the variables which affect the results.

For example, in SIMMOD, the FAA airport and airspace model, the phenomena being modelled is the movement of aircraft . The environment is a very well defined network of paths and intersections with well defined rules by which aircraft move, are prioritised, and pass from one geographic point to another.

There is no jostling, bumping, overtaking (without a path) and the nature of the surface over which these aircraft move is relatively un-important to the modelling exercise and the usefulness of the results. The behaviour of the aircraft is orderly, and always along pre-defined paths. All aircraft obey the surrogate air traffic controller in the model. The desired result for decision making from modelling airports and airspace with SIMMOD is the difference in operating times (or delays) from start to finish of the fleet of aircraft, given the decision variables of network layout, procedures, schedule of flights, etc.

The development of models such as SIMMOD are challenging from a programmers point of view but not from a designers point of view. Practically all aspects of the model can be observed and re-observed as often as necessary to improve the model or to achieve confidence that it represents reality sufficiently to allow evaluation of decisions. A probability distribution can be assigned to each variable and may be verified by current observations of the real phenomena. The model and each application can be validated and calibrated and therefore, its results are generally credible.

4. PASSENGER EVACUATION MODEL ENVIRONMENT

What type of environment are we dealing with in the evacuation phenomena ? Are there some rigidly defined "paths" for passengers to follow ? Are there rules which passengers have to follow ? Are flight attendants and other crew members like the air traffic controllers in an airport like model ? Do passengers necessarily follow the instructions of flight attendants ? How do we determine the basic movement of passengers and the interaction with crew members in order to model the movement ?

The answers to the above questions follow from the observation that the passenger evacuation environment is significantly more complex than most of the model environments encountered in aviation. The range of variables and the values they may assume are vastly more extensive and difficult to observe than the other phenomena. It should be admitted that

there are some elements of the passenger evacuation phenomena which are similar to the airport and airspace phenomena. These elements are easy to model and are verifiable.

It is useful to classify the passenger evacuation phenomena into the following[1]:

i) Static Elements

ii) Dynamic Elements

iii) Mobile Elements

iv) Behavioral Elements

Although all four elements are inseparable in the evacuation phenomena, it is instructive to classify them along these lines.

Static elements include the geometry of the cabin layout, including the seating plan, nominal exit types and locations, aisles and other open spaces, initial position of the passengers and crew etc. These should be elements which are easy to model and, as was noted from the demonstration of ARCEVAC, quite verifiable. However, if the result we seek from the complete model is the evacuation time, a measure of the injuries and survival rate, then we need to account for many other variables. These inlcude but are not limited to seat design, including pitch and the other obstructions such as carry on baggage, which, in a real emergency, may appear at locations other than originally placed. Damaged seats may also no longer allow movement as originally intended, and any additional exits that may come open in the emergency, and the potential assistance or injuries these spontaneous exits may cause, are additional variables for consideration.

Dynamic elements refer to the variables which appear during an evacuation and which vary during the evacuation phenomena. For example, fire propagation, smoke generation, toxic substance growth and in the case of a ditching, water intake are examples of the dynamic elements. Some of these we have been able to model as continuous variables (as opposed to discrete variables) while others we have not modelled satisfactorily due to an absence of observations and data or the range of variability associated with that element, for example, size and location of aircraft hull breach for a water landing.

Mobile elements are the people on board, including crew. These elements have some characteristics which we have intuitively been able to specify as relevant variables in he passenger evacuation phenomena. These are such variables as sex, weight, size, agility, constitution , normal speed of movement etc. However, we are not entirely certain , as yet, how these impact the exit times and survivability in the context of a mass exodus as opposed to the individual being subjected to various hazard phenomena. That is, while we can model an individual with certain characteristics and determine from the model the reaction of that

individual to various hazardous stimuli, in an emergency evacuation, we are not certain that the same characteristics will apply. For example, an agile person who can sprint a three minute mile may buckle under stress and fear from adjacent passengers. There are, of course, many more examples of characteristics of passengers and crew, with which we have difficulty in modelling.

Finally, the behavioral elements are the "rules" by which we expect the mobile elements to navigate within the constraints of the static elements and within the dynamic interaction with the mobile elements. Loosely, we may say that this is the human behaviour part of the phenomena, which we attempt to model. Here again, there are some components of human behaviour which are intuitive, or we have observed them repeatedly, and we have no difficulty in modelling them. For example, in a normal deplanement, passengers will remain seated until the seat belt sign is off, then get up from their seats, aisle seats first, and queue up in the aisles for an orderly departure. Now we can introduce to this model additional random variables such as times for picking up carry on baggage, door opeing times, seat belt off time compared to gate on time etc. Most of these are observable phenomena which we can model and verify.

In a real emergency, the situation is of course, quite different. Here we may point out that the type of and severity of the emergency is itself a random variable. We often refer to the variability of the severity and type of emergency evacuation exercise as "scenario." In any case, depending on the scenario, the behaviour becomes a function of many other independent variables, which we have barely begun to identify, let alone model. These include motivational effects, fear, previous training, decision making capabilities, influence over other passengers, assessment of risk capability, and a host of psychological and physiological variables which impact the ultimate movement and rate of transit from within the cabin to outside.

It is possible at this point to observe that the passenger evacuation modelling environment is unlike most other discrete event modelling environments in aviation . The emergency evacuation introduces additional variables, which are "highly random" and we have very limited data from the past and hopefully, from the future to develop models with the same reliability and applicability as, say, SIMMOD.

5. SUCCESSFUL COMPUTER EVACUATION MODELLING

From the previous discussion, it is clear that the totally flexible passenger evacuation model, which will allow us to meet all of the expectations suggested earlier is not near at hand. What is missing is an ability to verify that the models show the phenomena as they would occur in reality and produce results which can be compared to the real world results.

The most significant real evacuations' data base for other than normal deplanements, is that held by manufacturers for certification i.e. the 90 second evacuation with volunteers. In

addition, there are component elements which have been tested in a controlled environment and have produced useful data. These include egress through various doors, slides and chutes, in physical simulators at the FAA and Cranfield, and various training exercises at all of the major air carriers and manufactures around the world.

The implication here is that in the case of two of the expectations, specifically for certification and training, we have adequate data established so that mathematical and simulation models such as ARCEVAC can be verified against real tests. Therefore, for some scenarios, these models offer the promise of cost and injury cutting.

What has prevented us from going further with the "proof" of the current versions of these models is, beside lack of financial resources, the proprietary nature of the evacuation test data which is held by the manufactures. Were we given access to the data which resulted in both failed and successful tests, our models could be refined and fine tuned so that future testing could be done with these models with a high degree of confidence.

Specifically, for certification testing, it should be noted that the certification scenarios are "highly" controlled. The range of variability of the four elements is very limited. Therefore, these scenarios are ripe candidates for application of computer evacuation models.

The issue of training use of computer evacuation models is also ripe although there may be some confusion between the full motion simulators which are also computer evacuation training simulators and the computer evacuation simulation models. The training simulators such as those acquired by major air carriers for hands on training of crews (or that used by Cranfield University and CAMI for testing) provide tactical training for the individuals. That is, the individual participate in the simulation and learn what to do personally in the situation.

In using models such as ARCEVAC for training, the emphasis is on strategic issues. For example, we could demonstrate the effect of improper flight attendant positioning, or the effect of the number of flight attendants on "controlled" evacuations. It may be argued that intuitively, the more flight attendants, the faster the evacuation. However, animated models such as ARCEVAC show the relative merits of various procedural and placement strategies in a quantifiable way and allow some benefit-cost analysis to be performed. Therefore, these computer simulation models could allow management to "try out" various strategies of procedures and placements to determine optimal ones before training the crews hands on.

Aircraft design scenarios, in the context of our modelling exercises are closely related to the certification and training issues. Here, we are concerned with positioning and selection of exits, seats, galleys and other layout features. If the models are acceptable for certification, then they may also be used to test out various design alternatives to ensure that the designs meet the certification criteria, again with the attendant reduction in cost and risk of injury.

7. UNSUCCESSFUL COMPUTER EVACUATION MODELLING

Accident and survivability investigation was, in the beginning of our foray into evacuation modelling, one of the most desirable applications of computer evacuation modelling. We had expected that we would be able to recreate the accident scenario and, knowing the initial position of the occupants and the final outcome in an emergency (disaster), ascertain the possible interim event sequences which lead to the final result. From this we expected to gain insight into the history and shortcomings of the aircarft design and procedures, from which we could refine the design or procedures in order to minimise life loss, injury or damage.

The promise of doing this still holds but because the variability of the number and type of random variables is very large, and the data on previous accidents is sketchy at best, we are quite far from satisfying this expectation. The current computer models do not reflect a truly tested and verifiable tool. We have been able to model the occasional accident scenario and show the evacuation times and survivability to be comparable. This, however, is the first flight of the Wright brothers and we have a way to go before these machines fly with reliability and predictability.

We have attempted to post observe the event sequence during accidents and other real emergency evacuations by interviewing survivors . However, these sources of information have their own biases and may not reflect an objective account of the events during the evacuation. The external videos of real evacuations, where available, are only a very small part of the story, which does not give modellers enough to build the models. Never the less, we are continuing to explore the records from previous accidents to extract what we can of useful modelling bricks with which to improve the models.

It is instructive to compare the cabin accident and survivability investigation with that of the aircraft accident investigation. Until we had flight data recorders (FDR) and cockpit voice recorders (CVR), our knowledge of the accident event and the investigation were severely handicapped. Once we had the data from these two devices, we were able to build extremely reliable models and animation tools, which now form the basis of most accident investigation. The data also has been used to build models which allow "what if" analysis starting with the known aircraft conditions. The results have been used to improve aircraft design, pilot techniques, air traffic control procedures, and/or maintenance procedures.

Therefore, in order to advance the capability to investigate the cabin evacuation phenomena in real emergency evacuations, and advance the safety of this transportation system, we need explicit data like that available from the FDR and CVR.

8. CONCLUSIONS

As a community of designers, manufacturers, regulators and operators of commercial

aircraft, we have and continue to develop tools which allow us to test out our designs and certify them before the public steps into the production version of the aircraft. However, the improvements have sometimes come from learning which took place during some mishaps.

Computer evacuation models, particularly models such as ARCEVAC promise to give a powerful tool for testing and training on some types of evacuation scenarios, particularly those where the behaviour of passengers is controlled to some extent. On actual emergency scenarios, the capabilities of the models remain weak, and promise to remain so unless data to identify and describe the variables which occur in these phenomena can be acquired.

In the case of the controlled scenarios, we strongly urge the manufactures to share the certification data with the developers of the evacuation models in order to advance the cause of safety.

In the case of the emergency evacuation scenarios, it is clear we need to have the equivalent of CVR's and FDR's in the cabin if we are to achieve reliable models for the investigation of aircraft accidents and survivability. This means strategically located videos and voice recorders, and sensors for toxicity levels etc. Having recommended that these devices be placed in the aircraft cabins with crash proof recording media , it our hope that we never get data from these, and, if we have done our other jobs right, we never will. Therein lies another obstacle to the successful evacuation modelling for accident and survivability investigation.

1. Based on work done by Aviation Research Corporation in other aviation systems modelling.

OVERRIDING MOTIVATION

SAFER DESIGN AND OPERATION OF COMMERCIAL AIRCRAFT

ACHIEVED THROUGH

COMBINED EFFORTS OF DESIGNERS, MANUFACTURERS, REGULATORS, OPERATORS AND THE VICTIMS

SOMETIMES WE HAVE FAILED

DESPITE THE BEST INTENTIONS AND TALENTS WITHIN OUR GROUP. HOWEVER, WE HAVE ALWAYS LEARNED FROM OUR OVERSIGHT AND FAILURES.

PASSENGER EVACUATION CERTIFICATION CRITERIA

REAL LIFE TESTING SERVED US WELL UNTIL LARGE AIRCRAFT AND INJURIES. THEN, WE LOOKED FOR ALTERNATIVES.

EVACUATION COMPUTER MODELLING
AN ALTERNATIVE

ORIGINALLY (1950's) ONLY MATHEMATICAL MODELLING NOW POWERED BY COMPUTERS

ARCEVAC MODEL ORIGINALLY SPONSORED

BY

TRANSPORTATION DEVELOPMENT CENTRE

AND

TRANSPORT CANADA AVIATION

HIGH EXPECTATIONS FROM COMPUTER MODELLING

I) CERTIFICATION OF AIRCRAFT

II) AIRCRAFT CABIN DESIGN

III) ACCIDENT AND SURVIVABILITY INVESTIGATION

IV) FLIGHT CREW EVACUATION TRAINING

REAL LIFE TESTS

I) ARE POTENTIALLY DANGEROUS TO PARTICIPANTS

II) ARE EXPENSIVE

III) CANNOT BE CONDUCTED UNDER TRULY HAZARDOUS CONDITIONS

IV) CANNOT BE CONDUCTED ON AIRCRAFT IN THE DESIGN STAGE

V) CANNOT ACCOMMODATE CERTAIN TYPES OF PASSENGERS (EG. DISABLED AND ELDERLY)

VI) CANNOT REPLICATE MOST TYPES OF AIRCRAFT EMERGENCIES

VII) PROVIDE ONLY A LIMITED SAMPLE OF RESULTS

VIII) CANNOT BE CONDUCTED SEQUENTIALLY TO IMPROVE AIRCRAFT DESIGN OR EVACUATION PROCEDURES WITHIN REASONABLE LIMITS OF TIME, MONEY AND PEOPLE RESOURCES

IX) ETC

COMPUTER MODELLING PROCESS

1. Identify one or more measures of interest (objective function) which is output of model

2. Identify relevant input variables

3. Determine how they behave (typically probability distribution) individually

4. Determine how they interact with each other to produce results

5. Build model

6. Test model with actual input data and compare with actual results. If model results and real results similar, then model declared good and useful for similar inputs.

MODELLING ENVIRONMENT

High expectations of computer evacuation models perhaps not so much because of what we know of the environment of emergency passenger evacuations but more due to the success we have achieved with other simulation models in aviation.

For example, FAA'a airport and airspace design tool SIMMOD, used for designing and evaluating airport layouts, air space structure, flight schedules, ATC procedures etc.

The SIMMOD environment is a very well defined network of paths and intersections with well defined rules by which aircraft move, are prioritised, and pass from one geographic point to another.

There is no jostling, bumping, overtaking (without a path) and the nature of the surface over which these aircraft move is relatively unimportant to the modelling exercise and the usefulness of the results. The behaviour of the aircraft is orderly, and always along pre-defined paths. All aircraft obey the surrogate air traffic controller in the model.

The desired result for decision making from modelling airports and airspace with SIMMOD is the difference in operating times (or delays) from start to finish of the fleet of aircraft, given the decision variables of network layout, procedures, schedule of flights, etc

However, environment of passenger evacuation very different from that of, say SIMMOD.

What type of environment are we dealing with in the evacuation phenomena ?

Are there some rigidly defined "paths" for passengers to follow ?

Are there rules which passengers have to follow ? Are flight attendants and other crew members like the air traffic controllers in an airport like model ?

Do passengers necessarily follow the instructions of flight attendants ?

How do we determine the basic movement of passengers and the interaction with crew members in order to model the movement ?

To answer, consider the classification:

i) Static Elements

ii) Dynamic Elements

iii) Mobile Elements

iv) Behavioral Elements

All four elements are inseparable in reality. Instructive to classify them along these lines.

Static elements - geometry of cabin layout eg. exit, galley and seat locations etc.

Dynamic elements - vary independent of cabin design or procedures eg. fire, smoke, hull breach.

Mobile elements - crew and passengers

Behavioral elements - rules of behaviour given other elements

VARIABLES

In addition to the variables within each of the elements, the type of emergency provoking evacuation is itself a variable. Refer to the various values of this variable as Scenarios.

Passenger evacuation modelling environment is very different from most other discrete event modelling environments. The variables are highly random and real world phenomena are difficult to observe, both for developing the models and for verifying their validity.

SUCCESSFUL COMPUTER EVACUATION MODELLING

The totally flexible computer evacuation model to satisfy all of our expectations is not near at hand. However, to the extent that we can isolate scenarios for which large data bases of real world data exists, we can have successful models.

The most significant of these data bases is that held by manufacturers for certification and various component tests . Some also exists at Cranfield, CAMI and major air carriers who do training in mock up simulators.

Also noting that the certification tests are a highly controlled environment, the implication is that with access to the test data, our computer evacuation models could be fine tuned and refined to produce useful models to satisfy the expectations of reduced real life certification testing.

Aircraft design applications follow from the certification expectations and would, therefore, also be good candidates for computer evacuation models.

TRAINING APPLICATION

Emphasis is on strategic issues not tactical

Current training in computer controlled mock up simulators intended to train individuals on physical procedures.

Computer evacuation models such as the animated ARCEVAC intended to show the relative merits of various procedural and placement strategies in a quantifiable way and allow some benefit-cost analysis to be performed. Therefore, these computer simulation models could allow management to "try out" various strategies of procedures and placements to determine optimal ones before training the crews hands on.

Examples:

- **How many flight attendants for a particular evacuation time ?**
- **What is optimal positioning of flight attendants ?**
- **How should the post passenger evacuation inspection of cabin be performed to minimise on board time ?**

UNSUCCESSFUL COMPUTER EVACUATION MODELLING

Accident and survivability investigation was, in the beginning of our foray into evacuation modelling, one of the most desirable applications.

We had expected that we would be able to recreate the accident scenario and, knowing the initial position of the occupants and the final outcome in an emergency (disaster), ascertain the possible interim event sequences which lead to the final result. From this we expected to gain insight into the history and shortcomings of theaircraftt design and procedures, from which we could refine the design or procedures in order to minimise life loss, injury or damage.

The promise of doing this still holds but because the variability of the number and type of random variables is very large, and the data on previous accidents is sketchy at best, we are quite far from satisfying this expectation.

We have attempted to post observe the event sequence during accidents and other real emergency evacuations by interviewing survivors and examining reports. However, these sources of information have their own biases and may not reflect an objective account of the events during the evacuation.

CONCLUSION

Computer evacuation modelling for all controlled type of evacuations currently possible.

Accident investigation:

Consider progress in after CVR's and FDR's were installed. We now have models which can allow what if analysis based on the pre accident aircraft data and allow full animation of the events leading up to the accident.

What is needed is strategically located CVR and FDR type of equipment on board in the cabin, possibly video and voice recording with atmospheric samplers of toxicity etc. With enough data from these, we will be able to provide models which could be used to satisfy the accident and survivability expectation. However, if we have done our other jobs right, we will never get data from these devices even if do instal them on the aircraft. Therein lies the biggest obstacle to our achieving a credible and flexible computer evacuation model for accident and survivability investigation.

THE ROLE OF EVACUATION AND FIRE MODELLING IN THE DEVELOPMENT OF SAFER AIR TRAVEL.

Edwin R. Galea
CAA Professor in Mathematical Modelling
Fire Safety Engineering Group,
University of Greenwich,
London SE18 6PF. UK.

ABSTRACT

Computer based mathematical models describing the aircraft evacuation process and aircraft fire have a role to play in the design and development of safer aircraft, in the implementation of safer and more rigorous certification criteria and in post mortuum accident investigation. As the cost and risk involved in performing large-scale fire/evacuation experiments for the next generation 'Very Large Aircraft' (VLA) are expected to be high, the development and use of these modelling tools may become essential if these aircraft are to prove a viable reality. By describing the present capabilities and limitations of the EXODUS evacuation model and associated fire models, this paper will examine the future development and data requirements of these models.

INTRODUCTION

The mathematical simulation of evacuation and fire has a wide, and as yet largely untapped, scope of application within the aviation industry. The function of mathematical models is to provide insight into complex behaviour by enabling designers, legislators and accident investigators, to ask 'what if' questions.

Fire models could be used to determine the impact of the spread of fire hazards such as smoke, heat and toxic gases resulting from an accident and hence predict the development of life threatening conditions within the cabin. Fire models also have application in the development of fire protection and fighting strategies such as the development of water mist systems for aircraft.

Computer based mathematical models describing the aircraft evacuation process have a role to play in the design and development of safer aircraft and the implementation of safer and more rigorous certification criteria. Evacuation models also have application in post mortuum accident investigations where they could be used to suggest possible contributory mechanisms responsible for a particular accident. Associated with the development of computer based aircraft evacuation models is the need for comprehensive data collection/generation related to human performance under evacuation conditions. Furthermore, by interfacing fire models with evacuation models, contentious safety issues such as the introduction of passenger smoke hoods or cabin water mist systems could conceivably be examined in a more consistent and rigorous manner than current practise allows.

COMPUTER BASED EVACUATION MODELS

Under regulations set by national and international certification authorities, aircraft manufacturers must demonstrate that new aircraft designs or seating configurations will allow a full load of passengers and crew to safely evacuate from the aircraft within 90 seconds.

The accepted way of demonstrating this capability is to perform a series of full-scale trials using the

passenger compartments under question and an appropriate mix of passengers. Since 1969 more than 20 full-scale evacuation certification demonstrations have been performed involving over 7000 volunteers (OTA, 1993). The difficulties with this approach concern the threat of serious injury to the participates, the financial costs incurred, and by necessity, the inability to subject the passengers to hazardous conditions such as may result from a fire.

On a practical level, as only a single evacuation trial is necessary for certification requirements there can be limited confidence that the test - whether successful or not - truly represents the evacuation capability of the aircraft. In addition, from a design point of view, a single test does not provide sufficient information to arrange the cabin lay out for optimal evacuation efficiency. The lay out of the passenger compartment and the nature of the passenger population mix are essential ingredients in the search for optimal configurations. Considerations such as number of seats, number, type and location of exits, presence of seat obstructions in the vicinity of exits, number and width of aisles, number and location of cabin dividers, number of elderly and disabled passengers, nature of passenger disability, presence of luggage etc all must be taken into account.

The difficulties faced by the current range of 'wide-body' civil aircraft will be greatly amplified with the proposed next generation VLA. Designs currently being considered are capable of carrying 800+ passengers, consist of two or possibly three aisles and possess two or more passenger decks. Questions of seating arrangement; design of recreational space; number and location of internal staircases; number, location and type of exits, number of required flight attendants and flight attendant emergency procedures are just some of the issues that need to be addressed. The quantum leap in passenger capacity being suggested should also challenge some of our preconceptions in equipment design and operating procedures. For instance, in order to efficiently complete an evacuation, will it be necessary to extend emergency procedures to the marshalling of those passengers already on the ground? Quite apart from questions of emergency evacuation, issues concerning the appropriateness of proposed designs in allowing the rapid and efficient movement of passengers during boarding and disembarkation are a further essential design consideration. Furthermore, these requirements may potentially be in conflict with the requirements for emergency egress. Ultimately, the practical limits on passenger capacity are not based on technological constraints concerned with aerodynamics but on the ability to evacuate the entire complement of passengers within agreed safety limits.

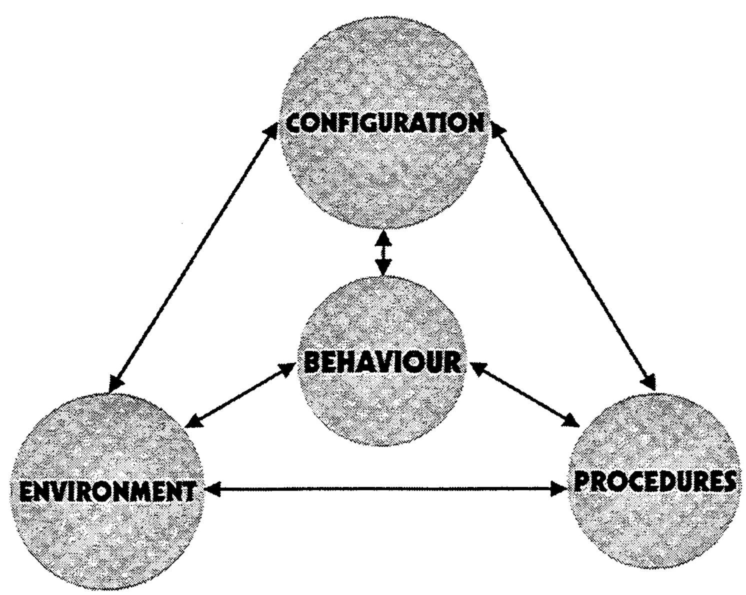

FIGURE 1. THE FOUR MAIN INTERACTING ASPECTS TO BE CONSIDERED IN THE OPTIMAL DESIGN OF AN ENCLOSURE FOR EVACUATION.

Computer based egress/evacuation models have the potential of addressing these shortfalls, however if they are to make a useful contribution they must address the configurational, environmental, behaviourial and procedural aspects (see figure 1) of the evacuation process (Snow et al, 1970).

Configurational considerations are those generally covered by conventional methods and involve cabin layout, number of exits, exit width, travel distance etc. In the event of fire, environmental aspects need to be considered. These include the likely debilitating effects on the passengers of heat, toxic and irritant gases and the impact of increasing smoke density on travel speeds and way-finding abilities. Procedural aspects cover the actions of staff, passenger prior knowledge of the cabin, emergency signage etc. Finally, and possibly most importantly, the likely behaviourial responses of the passengers must be considered. These include aspects such as the passengers initial response to the call to evacuate, likely travel directions, family/group interactions etc.

The EXODUS evacuation model (Galea and Galparsoro, 1993; Galea and Galparsoro, 1994; Galea et al,1995) attempts to address all four of the contributory aspects controlling the evacuation process. In order to understand how these components are brought together within an evacuation model and highlight their associated data requirements, a brief description of the EXODUS evacuation model follows. Examples of EXODUS predictions of evacuation from wide and narrow body aircraft under hazardous and non-hazardous conditions may be found in the cited references. While specifically addressing the data requirements of EXODUS, other aircraft evacuation models (Marcus, 1994) have a similar reliance on data.

A Brief Description of the Exodus Evacuation Model

EXODUS is an egress model designed to simulate the evacuation of large numbers of individuals from an enclosure. The model tracks the trajectory of each individual as they make their way out of the enclosure, or are overcome by fire hazards such as heat and toxic gases. The EXODUS model comprises five core interacting submodels, these are the **OCCUPANT, MOVEMENT, BEHAVIOUR, TOXICITY** and **HAZARD** submodels (see figure 2). The software describing these submodels is expert system based, the progressive motion and behaviour of each individual being determined by a set of heuristics or rules. The rules governing the simulation have been categorised into these five submodels. The software structure allows each of the rules which make up the submodels to be easily modified. It is this flexible modular structure that enables EXODUS to be easily updated when new rules are introduced.

The EXODUS software is written using C++ and is portable across platform types from PC to workstation running the WINDOWS or UNIX environments. The minimum recommended computer platform comprises a 25 MHz 486 PC with 8 Mbytes of memory. Run on this platform a simulation of a wide-body aircraft evacuation involving 400 occupants requires approximately two minutes CPU time.

Enclosure Description. Enclosures in EXODUS are made up from two-dimensional grids. The enclosure layout is constructed interactively and can be stored in a geometry library for later use. Each location on the grid is called a node, and each node may be linked to its nearest neighbours by a number of arcs, typically four or eight. Nodes which have distinguishing features may be assigned to special node classes for example, *aisle*, *stair*, *seat*, *door* etc. Occupants travelling over specific node types will be assigned attribute values appropriate for that node type, for example different maximum travel speeds and behaviourial responses would be appropriate for an individual travelling over an aisle node as opposed to a stair node.

Associated with each node is a set of attributes which define the state of the node. These are, temperature (degree C), HCN (ppm), CO (ppm), CO_2 (%), oxygen depletion (%) and smoke concentration. For each of these variables, two values are stored, representing the value at head height and near floor level. EXODUS does not include a component for **predicting** the generation and spread of fire hazards but simple distributes the

hazards generated by fire models.

Each node is also assigned an obstacle value which is a measure of the degree of difficulty in travelling over the node. A node representing an open space may have an obstacle value of one, while a node with debris may have a higher value of four for example.

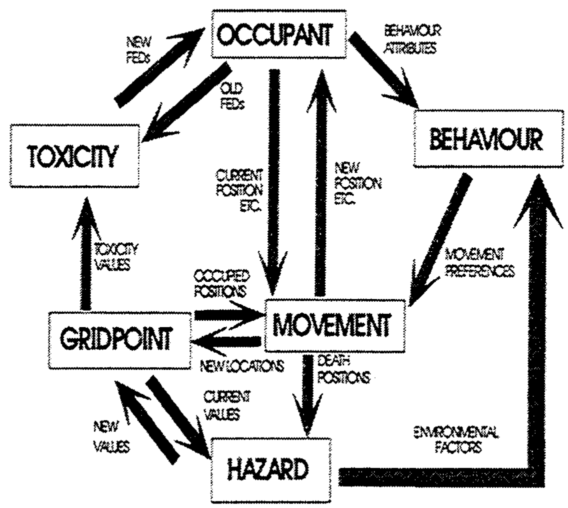

FIGURE 2. EXODUS SUBMODEL INTERACTION.

Submodel Description. The rules in EXODUS have been categorised into five component submodels, these are : **OCCUPANT, MOVEMENT, BEHAVIOUR, TOXICITY** and **HAZARD**. The submodels interact with each other and the geometry by exchanging various attribute values. The function of each of the five submodels will be briefly described.

The **OCCUPANT** submodel defines each individual as a collection of 20+ attributes which broadly fall into four categories, *physical* (such as age, weight, gender, agility etc), *psychological* (such as patience, drive etc), *positional* (such as distance travelled, PET etc) and *hazard effects* (such as FIN, $FICO_2$, FIH etc). These attributes have the dual purpose of defining each occupant as an individual and allowing their progress through the enclosure to be tracked. Some of the attributes are fixed throughout the simulation while others are dynamic, changing as a result of inputs from the other submodels.

The **MOVEMENT** submodel is concerned with the physical movement of the occupants through the different terrain types. Its main function is to determine the appropriate travel speed for the terrain type, for example - leap speed for jumping over seat backs. In addition it also ensures that the occupant has the capability of performing the requested action, for example - checks if occupant agility is sufficient to allow travel over node with particular obstacle value. The direction of travel is determined by the behaviour submodel.

The **HAZARD** submodel controls the enclosure environment and allows the user to specify the specific *simulation scenario*. The environmental aspects comprise the spread of fire hazards CO_2, CO, HCN, O_2

depletion, heat and smoke. The values for these are set at two heights, head height and knee height. Although EXODUS contains no specific component to generate the fire hazards, it has the capability to use input from fire models (Galea and Hoffmann, 1995) and experimental data. Scenario specific factors which are controlled by the Hazard model include aspects such as door opening/closing times.

The **TOXICITY** submodel functions only when fire hazards are present. Its' function is to determine the effect of fire hazards upon the occupants. The TOXICITY submodel currently models the effects of the narcotic fire gases, heat and smoke. The effect of the narcotic gases and heat are modelled using a Fractional Effective Dose (FED) model (Purser, 1988). During a simulation smoke is considered to reduce an occupants egress capability by decreasing their travel speed. The decrease in travel speed is based on the work of Jin and Yamada 1988. Furthermore, at a critical smoke density the occupants are forced to crawl. When this occurs the occupants are exposed to the fire hazards located at the lower level.

The **BEHAVIOUR** submodel determines an occupants response to the current prevailing situation. It is the most complex of the submodels. The behaviour submodel operates on two levels, *global* and *local*. The global behaviour provides an overall escape strategy for the occupants while the local behaviour governs the occupants' responses to their current situation. While attempting to implement the global strategy, an individuals behaviour can be significantly modified by the dictates of their local behaviour.

In the current implementation of EXODUS the global behaviour is fairly simple. This involves implementing an escape strategy which leads occupants to exit via their nearest serviceable exit or the exit to which they have been directed to by cabin staff.

The second level of Behaviour submodel function concerns the occupants' response to local situations. This includes such behaviour as determining the occupants initial response to the call to evacuate ie will the occupant react immediately or after a short period of time or display behaviourial inaction, conflict resolution, overtaking and the selection of possible detouring routes. The local behaviour is determined by the occupants attributes and as certain behaviour rules (eg conflict resolution) are probabilistic in nature, the model is unlikely to produce identical results if a simulation is repeated. Some of the local behaviour typically observed in EXODUS simulations will be discussed.

Response time - this is a measure of the time an occupant requires before they have moved out of their seat. It can involve a representation of an individuals reaction time, time to release seat restraint and time to stand upright. An individuals response time is part of the occupant attribute parameter set.

Conflict resolution - when two or more occupants via for space (usually in crowds) conflicts arise which must be resolved. Conflict resolution is the procedure by which this occurs within EXODUS.

EXODUS utilises a fine network of nodes to describe an enclosure. Each node is intended to represent the smallest amount of free space available for occupancy, essentially it is the space that a single individual can occupy. Thus only one occupant can occupy a node at a time. However, the situation often arises where two or more occupants may wish to occupy a particular node. An example to illustrate this is shown in figure 3 where three occupants wish to occupy the same node, two occupants are attempting to enter the aisle from their seats, while a third occupant, already in the aisle, is attempting to proceed. The three occupants (labelled 1,2 and 3) are attempting to occupy the indicated node and thus a three-way conflict arises.

Given that the travel distances and speeds associated with each of the conflicting occupants are such that there is no clear winner, the outcome of such a conflict would depend on the *drive* psychological attribute for each of the occupants. The *drive* is a measure of the assertiveness of an occupant and is part of the occupant

attribute parameter set.

Direction changes - occur as a result of three factors, staff influence, queuing/crowding and hazard concentration. Whenever an occupant is forced to remain stationary, for example due to crowding, the amount of time they remain stationary - known as wait time - is recorded. When an individuals wait time exceeds a critical level - defined by their patience attribute - the occupant attempts either to go around the blockage or move away, possibly towards another exit.

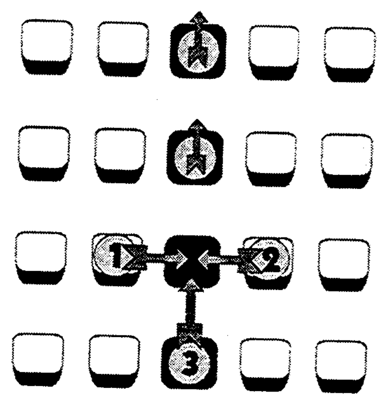

FIGURE 3. EXODUS CONFLICT RESOLUTION.

Overtaking - occurs as a natural consequence of the movement rules, specific overtaking algorithms are not required. An occupant blocked by a slower moving occupant will attempt to find an alternative neighbouring empty nodal position within the direction of travel.

Obstacle jumping - in the form of seat or debris jumping occurs when an occupant's wait time exceeds their patience and their agility attribute will allow them to do so. It is behaviour usually displayed by occupants caught between seats while aisles are blocked.

Staff Influence - occupants may be directed by flight attendants to take a particular route to an exit. In aircraft evacuation scenarios the flight attendants play a vital role in ensuing the smooth operation of the evacuation, directing occupants to exits or re-directing occupants away from unusable exits. This type of behaviour is achieved in EXODUS though the use of control nodes.

Exiting procedure - is dependent on two factors, exit width and exit flow rate. The exit width determines the maximum number of people which can pass through the exit simultaneously. The exit flow rate is used to determine the delay each occupant is likely to experience in passing through the exit. The exit flow rate may be obtained using one of three methods, the software can predict the exit flow rate on the basis of its rules, the exit flow rate can be prescribed through the use of experimental data or finally, a combination of rules and

experimental data can be used. Access to exits and congestion around exits while exerting a strong influence on overall exit flow rates are handled by features of the model previously described.

DATA ISSUES RELATING TO EVACUATION MODELS

Factual data regarding the evacuation process is essential to the development of computer egress models. Every component of the evacuation model just described relies on input from the real world in order to,

a) identify the physical, physiological and psychological processes which contribute/influence the evacuation process and hence formulate the appropriate rules,

b) quantify attributes/variables associated with the identified processes and finally,

c) provide data for model validation purposes.

The following is a list of data/information which is necessary for the development of aircraft evacuation models. While it is not definitive it addresses each of the three areas listed above.

1) Exiting Procedures: Develop relationships describing measured exit flow rates for particular exit types related to gender/size/age and nature of exiting method ie slide or platform.

2) Occupant Behaviour: Observation and characterisation of occupant behaviour, in particular, (a) route planning, (b) exit path recommitment, (c) influence of travel companions on behaviour and (c) change in behaviour dynamics as a function of increasing smoke density, reduced lighting, single or multiple aisled geometries.

3) Physiological Response: Establish which - if any - of the existing narcosis and irritant gas models is appropriate for use in aircraft fire situations and develop a linkage between passenger attributes and level of exposure to irritant and narcotic gases.

4) Response Times: Data which characterises the range of occupant response times for a variety of age/gender/agility groups. In particular need to consider, (a) time to release seat belts, (b) time required to assist others and (c) effect of smoke/darkness.

5) Travel Speeds: Data which characterises the range of occupant travel speeds for a variety of age/gender/agility groups. In particular need to consider travel speeds, (a) from window seat to aisle, (b) along aisle, (c) over seats, (d) over obstructions. This data can be characterised for level cabin floors, sloped cabin floors, as a function of smoke density (similar to the work of Jin and Yamada 1988) and in reduced light conditions.

6) Validation Data: Provide full-scale evacuation data from single and twin aisled configurations suitable for the validation of evacuation models.

Three forms of existing data are expected to provide some of the required information. Aircraft accident human factors reports produced by for example the NTSB and the AAIB, 90 second certification data held by the aircraft manufacturers, and large-scale experimentation devised to answer operational questions. Gaps in the knowledge this information provides can be filled by a combination of large- and small-scale targeted

experimentation.

Information from the first source is currently being collected by researchers from the Fire Safety Engineering Group (FSEG) at the University of Greenwich. The information is being collated into a database known as AASK which is an acronym for Aircraft Accident Statistics and Knowledge. At present, detailed information from NTSB and AAIB reports are being loaded into the database. This information is being collected from documented accounts of survivor interviews and factual reports.

Two types of passenger information is being collected. These involve:

(1) Simple factual information, for example,
- which exit passengers used (start and exit locations),
- location of fatalities and where they started from,
- nature of fatalities,
- location and nature of cabin debris.

(2) Passenger/Crew accounts of behaviour, for example,
- how quickly occupants responded,
- difficulty with belts - if they needed assistance,
- path taken to exit,
- did they encounter difficulty entering aisle from seat?
- did they pass over or around debris,
- did they go over seat backs? If so, why? exit and entry points noted.
- did they recommit after selecting a particular exit,
- did they experience difficulty seeing or breathing

The database can be used to analyze a single accident or a collection of accidents. As an example of the type of analysis which can be performed consider the following exit usage analysis performed on several of the accidents currently in the database.

Consider the B727 accident at Dallas on 31 August 1988 (Hammack, 1989). The aircraft crashed shortly after takeoff and was eventually destroyed by a postcrash fuel fire. The passengers and crew used two serviceable exits and three fuselage ruptures to make their escape.

Of the 89 survivors 81 passengers or 91% filled in a report. Of the 81 passengers reporting their exit usage only 18 passengers failed to use their nearest serviceable exit/opening. Of these passengers, nine passengers supplied reasons for this action. Three passengers were not aware of their nearest exit, two passengers decided that the congestion at the exit was too great and decided to try another, and four passengers were following someone else.

A similar analysis was performed over nine accidents since 1982 and involved a total of 238 passengers or 36% of the survivors. Of the 238 passengers who reported their exit usage only 32 passengers failed to use their nearest serviceable exit. Of these, 13 passengers supplied reasons for this action. Six passengers followed someone else, three cited the congestion at their nearest exit, and one followed a flight attendants instructions to move to another exit. While not complete, this analysis suggests that 92% of those reporting their behaviour used or had a good reason for not using their nearest serviceable exit.

This type of analysis is extremely valuable in aiding our understanding of the behaviour of people in real accidents and as such addresses the requirements of item (a) listed above and to a lesser extent item (b). It also provides essential insight to modellers attempting to simulate the evacuation process. While not yet complete,

the analysis just described provides some justification for adopting the global behaviour described in EXODUS and the nature of the local behaviour override. Detailed investigation of this type may also highlight behaviour which can be further examined through experimentation.

A further source of potentially useful data has been collected by the aircraft manufacturers through the certification process. However, due to the propriety nature of this data, it is difficult to assess its suitability for modelling purposes. While the bulk of the data may not be ideal, it may contain information partially addressing all three of the above areas. For example, by studying video footage of certification demonstrations it may be possible to collect information describing human behaviour such as,

- do passengers display difficulty with seat restraints,
- routes taken by passengers to exit,
- do passengers encounter difficulty entering aisle from seat?
- do passengers queue in aisles? if so for how long and where did the congestion occur? What was the nature of the congestion? What was the cause of the congestion?
- do passengers go over seat backs? If so, why? exit and entry points noted.
- do passengers recommit after selecting a particular exit,
- do exits become congested?
- do passengers hesitate at exits?
- is the behaviour of passengers under reduced lighting conditions significantly different to that expected under normal lighting conditions?

This information would partially address item (a). Detailed analysis of video footage may also reveal information which could be used to quantify attributes/variables used in the evacuation model thereby providing input to item (b) identified above. For example it may be possible to extract information relating to,

- how quickly passenger's respond to evacuation call,
- estimates of passenger maximum travel speeds,
- estimates of delay times at exits.

Finally detailed information concerning exit usage and evacuation times may be useful for validation purposes thereby addressing item (c). While the relevance of certification data to the development of models attempting to simulate evacuations under 'real' conditions may be questionable, it's value in the absence of more relevant data is obvious as is its relevance to the development of evacuation models capable of simulating certification conditions.

The third source of existing data is provided by large- and small-scale evacuation experiments. Over the past six years, the U.K. CAA has sponsored a series of large-scale competitive evacuation trials from a single aisled aircraft using a single exit (Muir et al, 1989). These trials were designed to answer specific operational questions concerning passenger behaviour relating to exit width and seat spacing at exits. This work has recently been extended to include competitive evacuations through multiple exits and the role of cabin crew intervention (Muir, 1995). This research is on-going and forms part of an international collaboration between the U.K. CAA and the USA FAA. Unfortunately, no detailed information of this type currently exists concerning competitive evacuations from wide-body aircraft.

To date most - if not all - the experimental effort in human evacuation research has been directed towards answering specific operational questions. Wherever possible this data has also been used to assist in the development of computer based evacuation models by providing insight into competitive human behaviour, more importantly however, they contribute to the general pool of data for model validation purposes. Thus, the data from this type of experimentation provides information which partially addresses item (c) above and to a lesser

extent item (a). Information from the Cranfield trials for example is being used as part of the EXODUS validation procedure (see figure 4). Other experimental research involving large-scale evacuation can provide detailed information to quantify essential model parameters and thereby address the requirements of item (b) listed above. For instance, recent work conducted by FAA CAMI has correlated the delay time associated with passengers of various weights, heights and genders, on passing through Type III exits (McLean and George, 1994). This data has been included within the EXODUS model as part of the exiting procedure options.

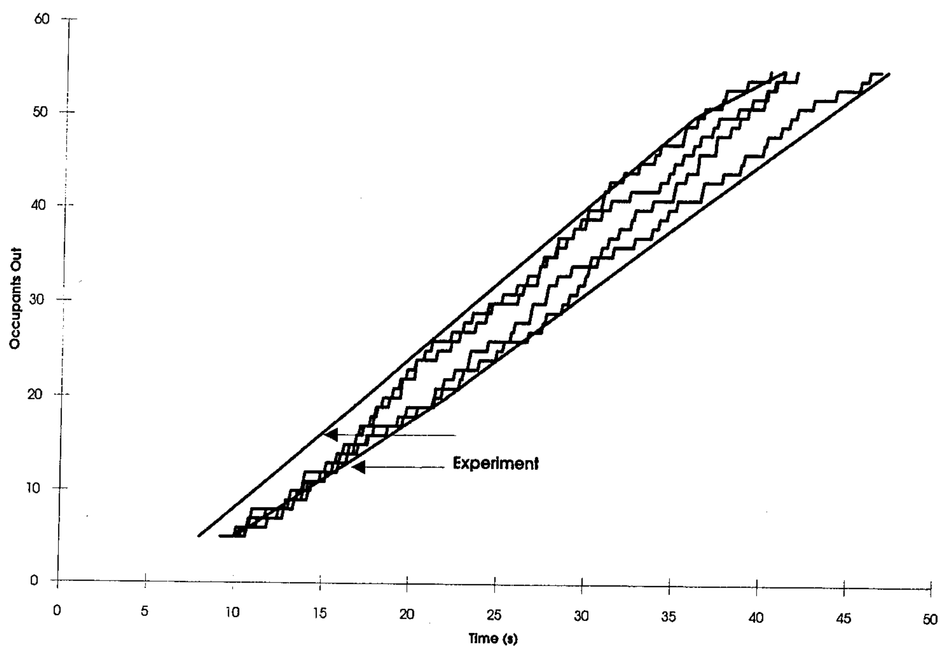

Figure 4 Evacuation curves depicting EXODUS predictions (stepped curves) and experimental envelope derived from Cranfield trials (B737 simulator) involving two forward exits and two assertive cabin crew.

While these three sources of data are providing modellers with valuable information, they are unlikely to satisfy all their data requirements. Targeted experiments must be devised to fill the gaps in our knowledge.

FIRE FIELD MODELS

Fire field modelling (Galea, 1989) has been a reality for twenty years, however its recent success in uncovering details of the fire mechanism responsible for the Kings Cross tragedy (Simcox et al, 1988) highlight its value as a fire analysis tool. Advocates of the procedure proclaim that the versatility of the technique - which it derives from its fundamental approach and minimal use of empiricism - make it an ideal design tool, useful in assessing the design of any inhabited enclosure for safety, and in the development of fire fighting strategies.

At the heart of the fire field simulation problem lies one of the most difficult areas in Computational Fluid Dynamics (CFD): the numerical solution of recirculating, three-dimensional turbulent buoyant fluid flow with heat and mass transfer. Field models differ from their simpler zone model (Galea, 1989) counterparts in that they employ CFD software that can describe and predict the flow of hot turbulent fire gases across a whole field of points in the enclosed compartment.

The equations which describe a field model consist, in general, of a set of three dimensional, time dependent, non-linear partial differential equations: the Navier-Stokes equations. These are essentially the same set of equations that aircraft designers use to design aerodynamic shapes such as wings. Fire field models employ CFD software to solve the fundamental equations of motion and conservation for the fire at discrete points in time and space. To facilitate this, the volume of the fire compartment is divided into thousands of small volumes or computational cells. The appropriate number is dependent upon the type of fire enclosure, the order of accuracy required and, ultimately, the speed of the computer and the size of its memory. A small room may require around 5000 cells, while the interior of a small passenger aircraft requires in excess of 50,000.

The equations describing the fire system are solved simultaneously in each cell to obtain the various parameters of interest such as temperature, pressure, gas velocities, smoke concentration etc. Thus, the model can display quantitative differences in the physical parameters throughout the computational grid. Using a three-dimensional framework of Body Fitted Co-ordinates (BFC), it is possible to construct realistically shaped fire enclosures. These could be as different as a spacious populated enclosure such as an aircraft cabin (Galea and Markatos, 1991; Galea and Hoffmann, 1995) or the confined environment of a cable duct. Validated fire models have the potential to be used by:

AIRCRAFT DESIGNERS, to assess the impact of new aircraft cabin layouts on the spread of fire hazards such as smoke under various fire scenarios. Fire models could be employed as design aids for the next generation VLA, bringing fire considerations into the early stages of aircraft design. For instance, VLA aircraft have been proposed which consist of two or three decks stretching along the entire length of the aircraft. In such aircraft multiple staircases linking the decks will be necessary. The role of these staircases in propagating smoke, heat and fire gases to regions otherwise clear of fire can be examined using fire models. The ramifications of burnthrough to other decks, cabin compartition and forced ventilation strategies on the associated spread of fire hazards could also be examined.

ACCIDENT INVESTIGATORS, to determine the impact of the spread of fire hazards such as smoke, heat and toxic gases resulting from an accident and hence predict the development of life threatening conditions within the cabin; and finally,

LEGISLATORS, to assess the suitability of new designs and fire protection and fighting devices such as water misting systems.

Current Research Areas in Fire Modelling

The primary application of current fire field modelling technology concerns the prediction of smoke and heat movement within fire enclosures. While the capabilities of current fire field are considerable much research effort is required to widen their scope of application.

Field modelling requires an enormous number of calculations to be performed, thereby necessitating the need for considerable computer power. Hundreds of hours of computer time may be required to perform even the simplest of aircraft fire simulations using current generation workstations. The high computational cost associated with fire field models is being tackled through advances in parallel computing hardware and software (Galea and Ierotheou, 1992; Galea et al, 1993; Galea and Hoffmann, 1995), thereby making these models more affordable and practical. The ability of fire field models to exploit parallel computing techniques will enable these models to be accurately and efficiently employed in large geometries such as B777 and A340 aircraft and their successors. Without this capability, compromises in mesh density and model complexity would be necessary in order to make simulations practical.

Even with parallel computers the exact solution of the equations governing turbulent flow is not practical. The equations describing the turbulent motion and the solution procedures to solve these equations are known; however, today's computer technology cannot provide the storage capacity or the computational speed required to allow their practical solution. The problem lies in the very nature of turbulence. The physical processes which control the growth and decay of turbulent motion are occurring on scales much smaller than the overall flow scales. Eddies responsible for the decay of turbulence in a gaseous flow are typically about 0.1mm. In order to describe the flow, it is necessary to work down to these small scales. This results in tremendous storage overheads and computational speed penalties.

If the CFD product is to be of any use to the engineer, the turbulent nature of the flow cannot be ignored. This problem, for the most part, has been overcome by the development of semi-empirical turbulence models (Launder and Spalding, 1972). These consist of differential or algebraic equations and associated constants. For most engineering applications the solution of these equations, together with the time averaged Navier-Stokes equations, provide a reasonable basis for the simulation of real turbulent fluids. More recent developments in turbulence modelling include Reynolds stress models, Large Eddy Simulations and Fractal based models (Dempsey et al, 1994), however these models are either extremely expensive in terms of CPU time or still under development.

In applications where it is necessary to predict apriori the concentration of various chemical products generated by the fire, or the physical spread of fire, or in situations where it is necessary to investigate how conditions in the enclosure affect the combustion process, a detailed combustion model must be implemented within the fire model.

The combustion process is extremely complex. The change from reactants to final products includes many intermediate reactions involving the formation and interactions of numerous short lived species and free radicals. In most instances, these intermediate products and their rates of creation and destruction, are not known. Turbulence further complicates the situation by influencing the mixing of reactants and products. Consequently, in most fire models combustion is assumed to follow a global, one-step chemical reaction mechanism (Magnussen and Hjertager, 1979), in which fuel reacts with oxidant to give product. The rate of reaction is controlled solely by the turbulent mixing of fuel and oxidant which is determined from calculated flow properties. This approach, while only approximating the combustion process, does give satisfactory results for relatively simple gaseous fuels. The prediction of flame spread over complex solid surfaces such as aircraft seats, cabin wall and floor linings is currently beyond the scope of field modelling technology and is receiving considerable interest from research groups throughout the world.

Another area of interest is the modelling of fire suppressant systems. Such scenarios have obvious application to the development of aircraft water mist systems for use either in cabins or as a replacement for existing halon based systems in cargo holds (CAA, 1993; Hill et al, 1991). Using the field modelling approach it is possible to simulate the action of water sprays in a fire compartment.

In this case there are now two interacting physical phases, the gas phase involving the general fluid circulation of the hot combustion products and the liquid phase, representing the evaporating water droplets. The numerical procedure of the fire model must be adjusted to take into account these interacting phases. This set of equations now includes the interphase processes of drag, heat and mass transfer between the liquid and gaseous phases.

One approach to the simulation of these interacting phases is the Euler-Lagrange methodology (Mawhinney et al 1995). In this approach the gas phase is modelled using standard CFD techniques while the discrete phase (water droplets) are modelled using a Lagrangian particle tracking scheme. The motion and properties of individual droplets or packets of droplets are tracked either until they evaporate or come into contact with a

surface. Finally, the two phases are coupled using the PSI-Cell method. In this method the particles mass, enthalpy etc are noted as it enters and leaves each cell in the computational domain. Any changes in the values of these quantities are due to gas/droplet exchange and are calculated and added to the appropriate cell in the gas phase as sources. In this manner the temperature and gas flow will effect the trajectory and evaporation rate of the water particles and the particles will react back onto the temperature and velocity field of the gases. This approach has been adopted by the FSEG and forms the basis of a spray model for use in aircraft fire applications. The model includes such parameters such as flow rates, droplet size, throw angle, orifice size etc.

CONCLUSIONS

The conclusions of this paper are divided into two parts, the first dealing with evacuation models and the second with fire models.

Evacuation Models

If aircraft evacuation models are to have a role to play in the development of safer air travel it is essential that the aviation industry cooperate in the furnishing of data essential to their development. In particular the following emphasis should be placed on the gathering of this data,

1a) A high priority continue to be given to accident investigators for the collection of human factors data relating to passenger survivability.

1b) Where possible, interview procedures be modified to allow the collection of data specifically of interest to modellers.

1c) The detailed study of existing aircraft accident reports by modellers be continued.

2a) Access be given to propriety 90 second certification data held by the aircraft manufacturers for the purposes of evacuation model development.

2b) The commencement of a detailed analysis of 90 second certification data by evacuation modellers.

3) The detailed analysis of existing evacuation experimentation data by modellers be continued.

4) A range of large- and small-scale evacuation experiments be conducted targeted at providing the remaining data required for the development of evacuation models.

Fire Models

While still requiring further development, fire field modelling has an impressive range of capabilities to offer the aerospace industry. While existing aircraft fire field models rely on imposed fire descriptions, they can be used to describe the spread of fire hazards such as heat and smoke within the aircraft and thus reveal how potentially hazardous conditions develop.

The demonstrated ability of fire field models to exploit parallel computing techniques will enable these models to be accurately and efficiently employed in large geometries such as B747 and A340 aircraft and their successors. Without this capability, compromises in mesh density and model complexity would be necessary in order to make simulations practical. The linking of aircraft fire models to other predictive models such as water

spray and evacuation models also promises to be of great benefit to the aviation industry.

Fundamental research is however still required in a number of areas. For example, combustion modelling and flame spread over solid surfaces are two areas which require considerable effort as well as the thorough experimental validation of existing models.

ACKNOWLEDGEMENTS

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INFLIGHT EMERGENCIES SESSION

Wednesday, November 15, 1995

Session Chairman
Nick Butcher
U.K. Civil Aviation Authority
Safety Regulation Group

ABSTRACT

"Cabin Crew Incident Reporting to the NASA Aviation Safety Reporting System"

Linda Connell
Flight Management and Human Factors Division
Aviation Safety Reporting System
NASA Ames Research Center
California, USA

The NASA Aviation Safety Reporting System (ASRS) was established 1976. Since that time the ASRS has served as a national reporting system on aviation incidents occurring within the National Airspace System. This system has been used by all members of the aviation system, including cabin crew members. Currently, the ASRS is receiving approximately 30,000 reports per year. The majority of these reports are submitted by pilots flying all types of aircraft, including general aviation. However, there are relatively low levels of incident reporting from air traffic controllers, mechanics, dispatchers, and cabin crew.

This presentation will include information on the current reporting levels, the types of reports received, the utilization and benefits of the data to aviation safety, and the on-going human factors research efforts. The current improvements within the ASRS will be discussed including the development of new reporting forms; one specially designed for cabin crew.

CABIN CREW INCIDENT REPORTING
NASA Aviation Safety Reporting System

International Conference on

Cabin Safety Research

Atlantic City, NJ

November 15, 1995

Linda J. Connell

Aerospace Human Factors Research Division

NASA Ames Research Center

(Courtesy Presenter: Ms. Nora Marshall)

ASRS: CONCEPT AND MISSION

The ASRS receives, processes and analyzes voluntarily submitted aviation safety reports from pilots, air traffic controllers, and others. Reports submitted to the ASRS describe both unsafe occurrences and hazardous situations. ASRS's particular concern is the quality of human performance in the aviation system. ASRS uses the information it receives to remedy reported hazards, to conduct research on pressing safety problems, and to otherwise further aviation safety. ASRS reporters are assured confidentiality, and to encourage reporting, the FAA extends limited immunity to individuals who report unintentional rule violations.

ASRS PURPOSE

- Identify Deficiencies & Discrepancies In The National Aviation System
  - Objective: Improve The Current Aviation System
- Provide Data For Planning & Improvements To The National Aviation System
  - Objective: Enhance The Basis For Human Factors Research & Recommendations For Future Aviation Procedures, Operations, Facilities And Equipment

ASRS PROGRAM SCOPE

The ASRS Program Applies To National Aviation System Incidents, such as:

- Air Traffic Control Procedures
- Cabin Safety
- Pilot/Controller Communications
- Airport Aircraft Movement Area
- Near Midair Collisions
- Aircraft Maintenance

ASRS PROGRAM ELEMENTS

NASA Aviation Safety Reporting System

- Voluntary
- Confidential
- Non-Punitive

ASRS/FAA IMMUNITY CONCEPT

(FAA Advisory Circular AC No. 00-46C)

c. The filing of a report with NASA concerning an incident or occurrence involving a violation of the Act of the Federal Aviation Regulations is considered by the FAA to be indicative of a constructive attitude. Such an attitude will tend to prevent future violations. Accordingly, although a finding of a violation may be made, neither a civil penalty nor certificate suspension will be imposed if:

(1) The violation was inadvertent and not deliberate;

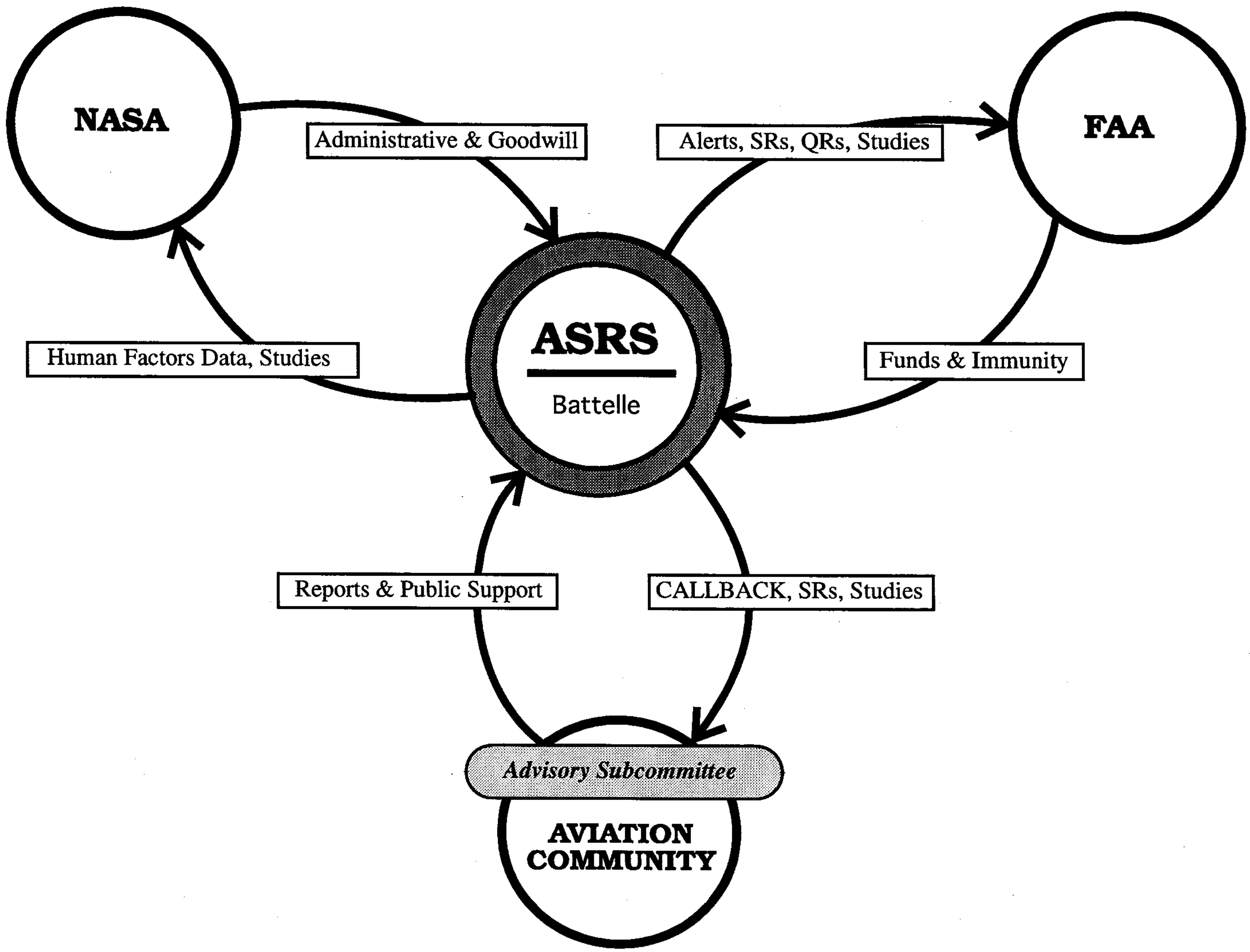
(2) The violation did not involve a criminal offense, or accident, or action under Section 609 of the Act which discloses a lack of qualification or competency, which are wholly excluded from this policy;

(3) The person has not been found in any prior FAA enforcement action to have committed a violation of the Federal Aviation Act, or of any regulation promulgated under that Act for a period of 5 years prior to the date of the occurrence; and

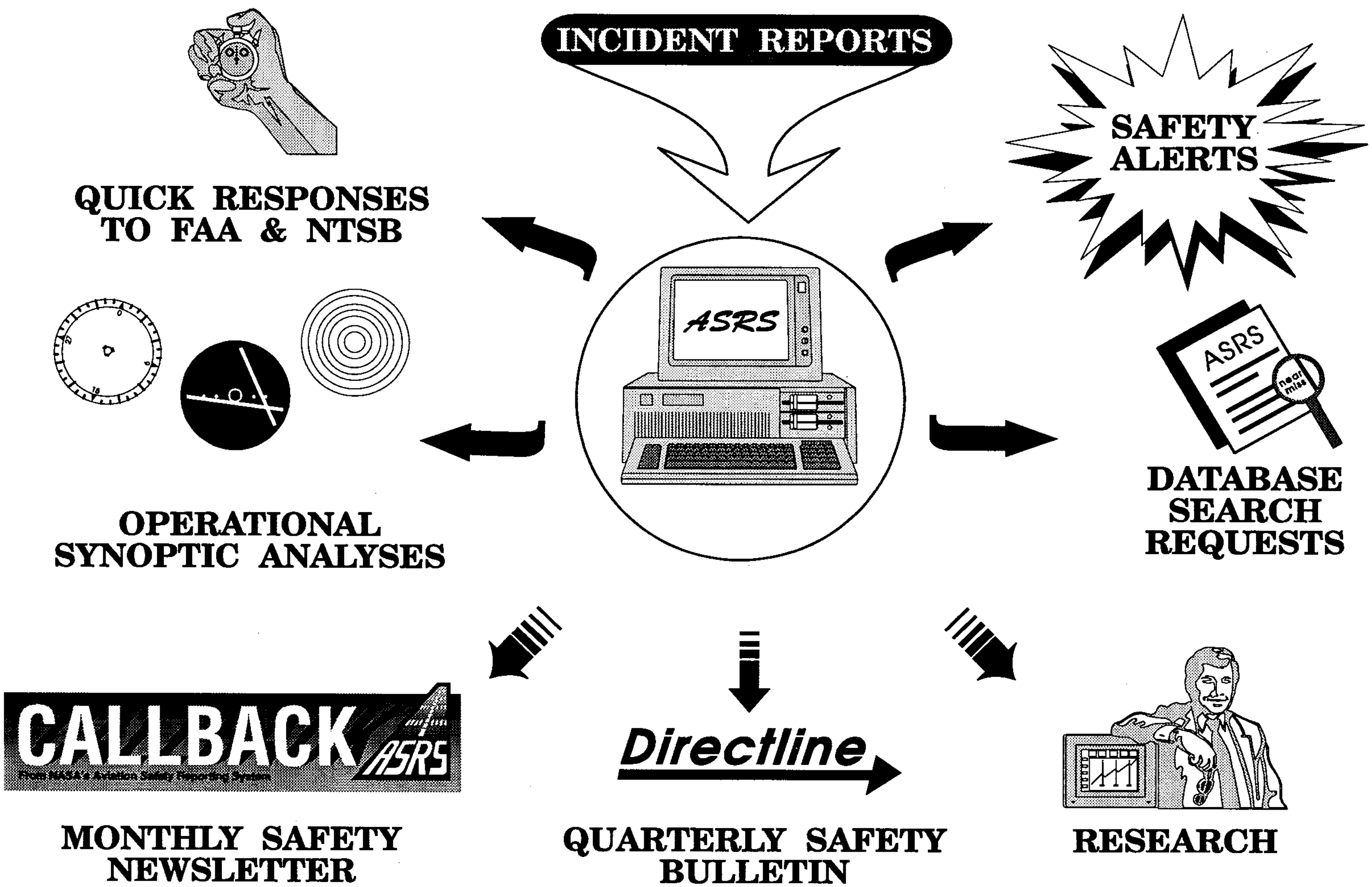
(4) The person proves that, within 10 days after the violation, he or she completed and delivered or mailed a written report of the incident or occurrence to NASA under ASRS. See paragraphs 5c and 7b.

NOTE: Paragraph 9 does not apply to air traffic controllers. Provisions concerning air traffic controllers involved in incidents reported to NASA under ASRS are addressed in FAA Order 7210.3J, Facility Operation and Administration.

BENEFICIARIES AND PROVIDERS



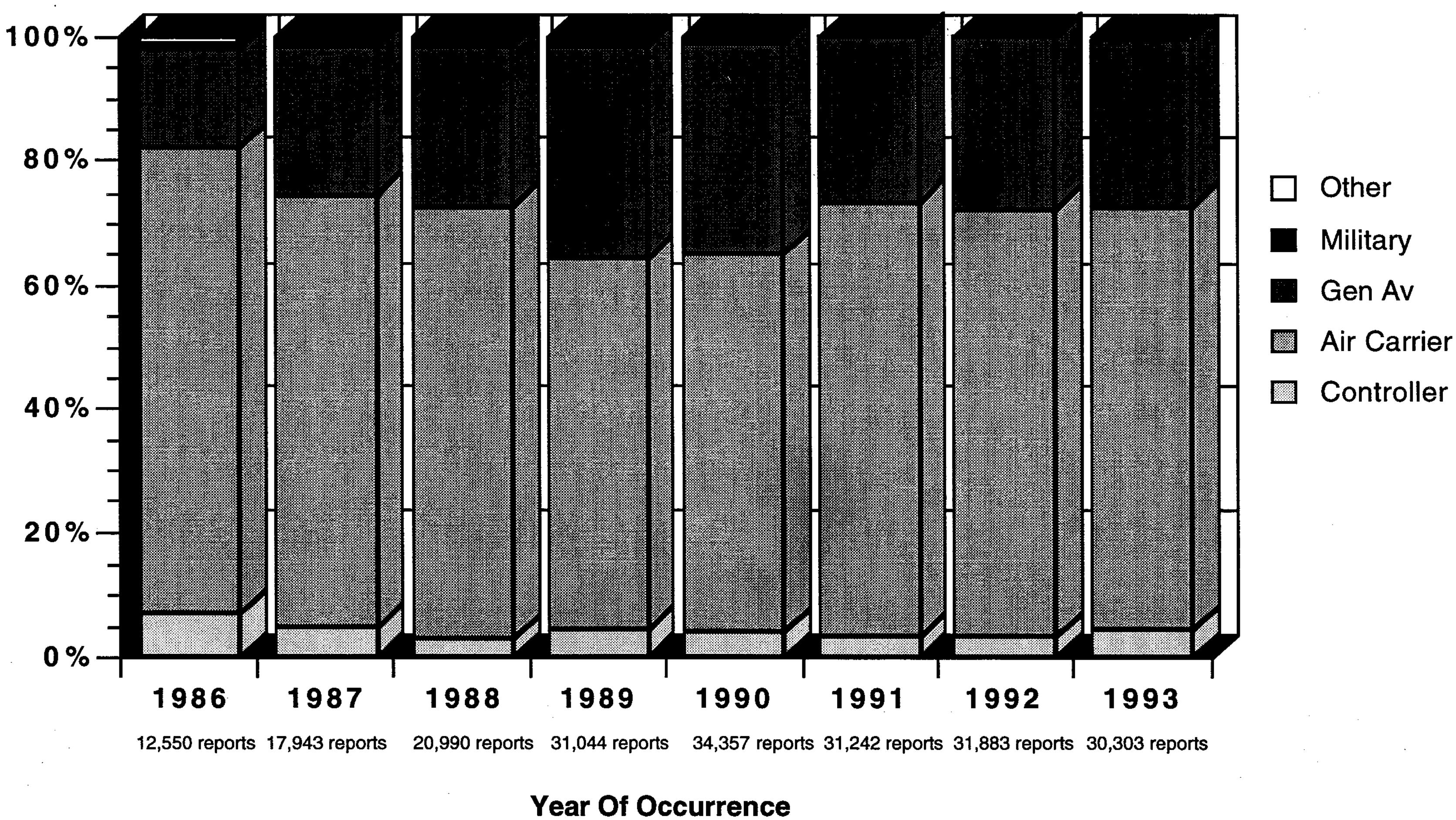
ASRS PRODUCES A WIDE VARIETY OF SERVICES & PRODUCTS FOR THE AVIATION COMMUNITY



REPORTING

ASRS receives reports from pilots, air traffic controllers, air carrier inspectors, cabin attendants, mechanics, and a variety of other individuals. ASRS's report intake was robust from the first days of the program, averaging approximately 400 reports per month. In recent years, report intake has grown at an enormous rate. It now averages 575 reports per week and more than 2,500 reports per month, and ASRS expects to receive over 30,000 reports next year.

ANNUAL INCIDENT REPORTER DISTRIBUTION

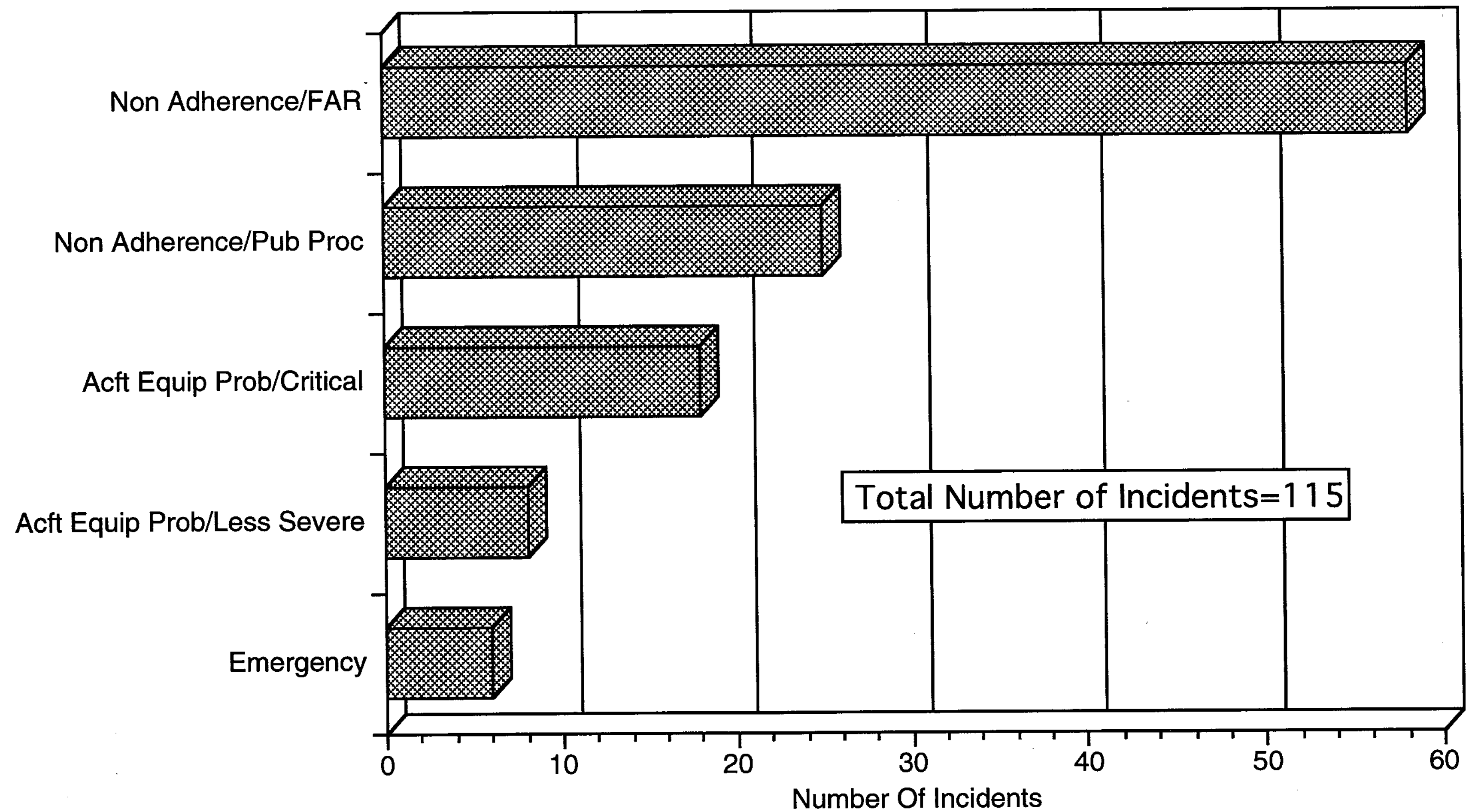


CABIN CREW REPORTING vs TOTAL ASRS REPORTING
January 1986 - April 1995

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995*
Reports from Cab Attendants	17	18	20	11	7	8	9	14	10	7
Reports Referenceing Cab Attendant Involvement	60	47	55	74	102	113	129	183	216	107
Total Database Incidents	8992	13616	16384	24953	27731	25037	25869	24410	26411	4524

* Data for 1995 are incomplete

CABIN CREW REPORTED INCIDENTS - ANOMALIES*
January 1986 - April 1995



* Categories are not mutually exclusive

FUTURE CABIN CREW REPORTING

- Many current efforts in human factors and safety at NASA, FAA, ATA, and NTSB would be greatly enhanced with increased incident reporting from cabin crewmembers.
- Information on safety related incidents is needed to support ongoing airline industry/government activities and research.
- Incident reports can be utilized by all interested organizations, unions, airlines, and others to improve cabin safety.
- A new NASA ASRS reporting form is being specifically developed for Cabin Crew (DRAFT NASA ARC#277C).

IDENTIFICATION STRIP: *Please fill in all blanks to ensure return of strip. NO RECORD WILL BE KEPT OF YOUR IDENTITY.*
This section will be returned to you.

(SPACE BELOW RESERVED FOR ASRS DATE/TIME STAMP)

TELEPHONE NUMBERS where we may reach you for further details of this occurrence:

HOME Area ____ No. ______ - ________ Hours ______

ALTERNATE Area ____ No. ______ - ________ Hours ______

NAME ________________________

ADDRESS/PO BOX ________________________

____

CITY ____________ STATE ______ ZIP ______

TYPE OF EVENT/SITUATION ________________________

DATE OF OCCURRENCE ________________________

LOCAL TIME (24 hr. clock) ________________________

DO NOT REPORT AIRCRAFT ACCIDENTS AND CRIMINAL ACTIVITIES ON THIS FORM -- ACCIDENTS AND CRIMINAL ACTIVITIES ARE NOT INCLUDED IN THE ASRS PROGRAM AND SHOULD NOT BE SUBMITTED TO NASA. ALL IDENTITIES CONTAINED IN THIS REPORT WILL BE REMOVED TO ASSURE COMPLETE REPORTER ANONYMITY.

PLEASE FILL IN APPROPRIATE SPACES AND CHECK ALL ITEMS WHICH APPLY TO THIS EVENT OR SITUATION

REPORTER

- O Flight Attendant (FA)
- O Trainee
- O FA in charge
- O Off-Duty FA
- O Extra FA
- O Other ________

EXPERIENCE

- Total years as Flight Attendant ________
- Total years as FA with your current airline ________
- Number of aircraft types currently qualified to work on ________
- Percent of duty time in past year on aircraft type involved ________

FLIGHT INFORMATION

Type of aircraft (Make/Model) ________________________
number of seats ______ number of pax on board ______ number in cabin crew ______
number of exits: floor level ______ window ______ tailcone ______

Flight segment flight origin ________ destination ________ departure time ______
time since takeoff ______ hrs/mins nearest city/state (if known) ________

Cabin activity (check all that apply)
- O boarding
- O beverage service
- O cart service
- O movie
- O deplaning
- O meal service
- O tray service
- O other ______
- O safety related duties, specify ________________________

FIRST FOLD

FIRST FOLD

OPERATOR	FLIGHT PHASE		WEATHER		LIGHTING	
					CABIN	OUTSIDE
O air carrier	O predeparture	O descent	O clear	O cloudy	O bright	O daylight
O commuter	O taxi	O approach	O rain	O fog	O medium	O night
O corporate	O takeoff	O landing	O turbulence	O snow	O dark	
O charter	O climb	O gate arrival	O thunderstorms	O ice		
O other ______	O cruise	O other ______	O unknown			

EVENT CHARACTERISTICS

Reporter's location in aircraft at time of event ________________________

Reporter's activity at time of event ________________________

Was a passenger directly involved in the event? O Yes O No

Was fire/smoke involved in the event? O Yes O No

Did this event result in an injury? O Yes O No
to passenger? O Yes O No
to crew? O Yes O No

Was there an evacuation during or as a result of this event? O Yes O No

DESCRIBE EVENT/SITUATION

Keeping in mind the topics shown below, discuss those which you feel are relevant and anything else you think is important. Include what you believe really caused the problem, and what can be done to prevent a recurrence, or correct the situation. (CONTINUE ON THE OTHER SIDE AND USE ADDITIONAL PAPER IF NEEDED)

CHAIN OF EVENTS
- How the problem arose
- How it was discovered
- Contributing factors
- Corrective actions

HUMAN PERFORMANCE CONSIDERATIONS
- Perceptions, judgments, decisions
- Actions or inactions
- Factors affecting the quality of human performance

NASA ARC #277C

CABIN CREW

NASA CONTACT AND CURRENT STATUS

- Linda Connell, Aviation Safety Reporting System
- Mail Stop 262-4
- NASA Ames Research Center
- Moffett Field, CA 94035-1000
- (415) 604-6654

INTEGRATING SAFETY AND SYSTEMS:
The Implications for Organizational Learning

Callum MacGregor
Senior Safety Services Investigator,
British Airways, England

Dr Heather Höpfl
Research Director, Bolton Business School
Bolton Institute, England

ABSTRACT

This paper considers problems that occur in aircraft operations associated with information difficulties at the human interface, using reference data from air safety incident reports and drawing on recent work by Turner, Reason, Toft, Pedler et al. Attention is given to events involving "decoy" problems and incidents where perceptual errors have been a factor and/or where there have been difficulties interpreting information.

Contextual models are used in order to analyze the various ways that information can be processed and categorized, leading towards the integration of safety, training, and operational activities within the airline.

The implications of the study for Organizational Learning are considered in relation to the development of a safety culture and safety management.

* * *

The past decade has seen a series of major disasters affecting such diverse technologies as nuclear installations, chemical plants, oil tankers and ferries, railway networks, oil platforms and, of course, commercial and military aircraft. Despite the obvious differences in the industries involved and their technologies, it has become apparent from the analysis of such disasters that, at a contextual level, there are many common characteristics (Reason, 1990). As a result, recent attention has been given to the socio-technical aspects of safety systems, to the complexity of the contributory causes in accident analysis, to the multiplicity of ways in which systems can fail, to the predominance of human factor contributions to failure, to perceptual and information difficulties and, not least, to the appreciation of the historical dimension, the fact that disasters often have a long incubation period. This widening of the boundary around safety issues has resulted in a move away from what Toft has described as a "propensity to look for simple causal solutions ...... shaped by the technical concerns of the engineering community" (Toft, 1992) towards a commitment to the recognition of the social and organizational context of incidents and accidents.

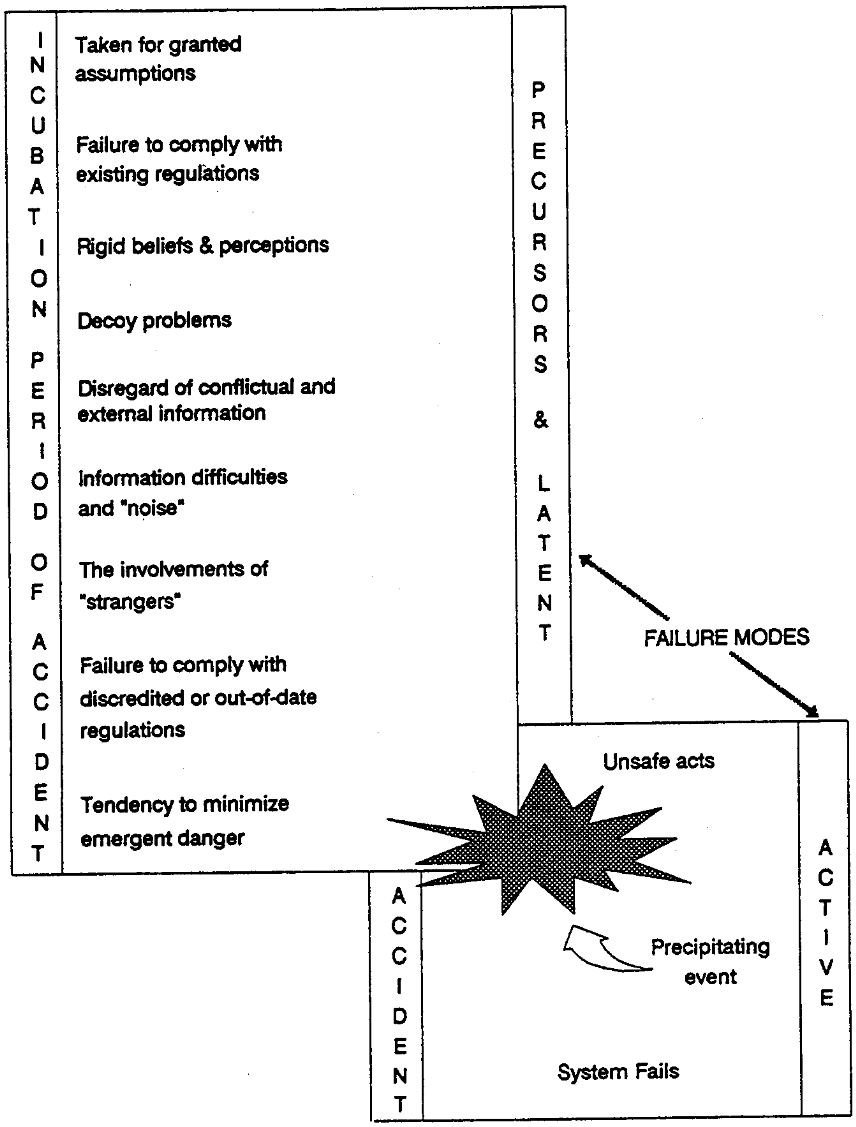
These are not issues which have escaped the concern of the Flight Safety Foundation and, in a paper presented to the 43rd IASS Conference in Rome in 1990, Captain Heino Caesar, General Manager, Flight Operations, Inspection and Safety Pilot for Lufthansa, identified a number of critical organizational issues with direct significance for air safety and specifically comments on an over-reliance on technical and technological developments in the pursuit of improved air safety, at the expense of a more systematic analysis of the organizational context to conclude "that future incidents and accidents must be far more carefully analyzed as to human performance factors, to produce tools to develop failure avoidance strategies, and to show how the duties were performed with a social, organizational and cultural context" (op.cit, p.4). These are important issues for safety management and they require a detailed examination of the reciprocity between social and technical aspects of operating systems in order to ensure that benefits feed into the ways in which an organization activates its "organizational memory" and provides for "organizational learning".

The following examination of the wider systems context has been written to complement the paper presented by Captain Colin Seaman, Head of Safety, British Airways, at the 44th IASS, Singapore 1991, The British Airways Safety Information System. In his paper, Captain Seaman outlined the philosophical commitment to changes in safety management which he and his staff have pioneered in Safety Services in British Airways and detailed the ways in which BASIS has been designed and developed to tackle the complexity of safety data received by the department and to provide dynamic and immediate ways of accessing, cross-referencing and disseminating usable information to line managers. The department made a critical assessment of its role and structure and concluded that a radical change was needed in its system of accident and incident reporting and analysis. Starting from an inherited forty-seven filing cabinets full of largely redundant and unusable safety data, the department progressed rapidly to a newly designed safety information system which was to provide the active memory of the organization on matters of safety. BASIS was designed to maximize data capture and to identify areas of significant risk. It was also designed to provide information regarding the effectiveness of decision making with a bearing on flight safety and to facilitate rapid distribution of safety information to line managers. Moreover, being designed by experienced end-users of safety information, BASIS incorporates features which offer conspicuous analytical benefits: a risk index, a detailed reference system and a trend analysis function based on operational and technical keywords; patterns of human factor incidents can be analyzed and implications for training needs and equipment design and modification can be detected. The evident success of the BASIS system and the interest it has generated outside the company (and, indeed, outside the airline industry) attests to the range of practical applications to which the system can be put. In part, this is because BASIS was designed by people with extensive experience of the context in which the system was to be located, with practical working knowledge of incidents, perceptions, technical problems, human factors, the social and organizational context and so on. "The strength of BASIS lies not in the storing of information, but in using it to ask questions about the operation and to provide some answers ...... a practical probing into all the available data with the intention of uncovering the unknown and undesirable" (Holtom, 1991).

This paper attempts to probe ways in which the "unknown and undesirable" might be construed in order to explore the dynamic tensions between those things which BASIS can tackle and, in modification and development, might reasonably incorporate and those aspects of the system which are destined always to remain outside the scope of precise data capture but which feature in the interpretative domain of the broader system. This appreciation of the dialectics of safety information, between the rational and irrational aspects of systems, between those categories which can be used to capture and aggregate data and those which remain elusive, is important from the point of view of making manifest those aspects of safety systems which are irreducible and, therefore, potentially the most threatening. Reason, among others, points to the significance of the "latent failures" (op.cit: p.28) which only become evident when they occur with a "precipitating event" (Turner, 1978) which causes the system to fail. Moreover, Reason contends that "there is a growing awareness ..... that attempts to discover and remedy these latent failures will achieve greater safety benefits than will localized efforts to minimize active failures" (Reason, op.cit: p.476-7), for example, in the nuclear industry, failure to perform necessary maintenance activities, i.e. latent failure, has played a major role in incidents and accidents in nuclear installations (Rasmussen, 1980).

Reason has used the analogy of the "resident pathogen" to describe the preconditions for catastrophic failure, which he argues, like pathogens in the human body which predispose to disease, predispose organizations to disaster. The point is that such "pathogens" produce unforeseen/unforeseeable contributions to disease and, by association, to systems failure. According to Reason, the likelihood of an accident is a function of the number of pathogens in the system. The more complex and tightly coupled the system (Perrow, 1984), the greater the number of pathogens. Consequently, Reason argues that safety specialists need to direct their attention to the identification and neutralization of latent failures, rather than attempting to prevent "active" or front line failures.

In a similar way, Turner (1978) has argued that large-scale accidents have an "incubation period" in which there are a series of unnoticed events which are likely to run counter to established beliefs about the way that the system operates or that risks are defined. Turner encourages safety researchers to concern themselves with "the cultural disruption which is produced when anticipated patterns of information fail to materialize" in order to develop an appreciation of the way in which individuals "gradually come to develop and rely on a mistaken view of the world" (op.cit: 193). "The problem of understanding the origins of disaster is the problem of understanding and accounting for harmful discharges of energy which occur in ways unanticipated by those pursuing orderly goals" (op.cit: 201).



Based on Turner (Op cit. p 102 - 103) and Reason (Op cit.: p479).

Figure 1

Turner goes on to argue that the incubation period ends when some precipitating event draws attention to the discrepancy between the environment as it is believed to be and the environment as it actually is. This forces into the open the "hidden, ambiguous or anomalous events which have accumulated during the incubation period" (op.cit) producing a sudden shift in information levels. Consequently, Turner is arguing that relevant information is vital to the prevention of disasters. However, this is more difficult than it might at first seem. Some information is completely unknown, some may be known but not fully appreciated, some information may be available to some members of the organization but not to others, some information may be available but cannot be appreciated within current modes of understanding (op.cit: 195).

INFORMATION GAPS

- TOTALLY UNKNOWN
- KNOWN BUT NOT UNDERSTOOD/APPRECIATED
- KNOWN BY SOMEONE BUT NOT AVAILABLE TO SYSTEM FOR VARIOUS REASONS AND THEREFORE NOT ACTED UPON
- AVAILABLE BUT UNABLE TO ENTER OR BE DETECTED BY EXISTING SYSTEM

Figure 2

The first case is difficult to deal with: such information may only reveal its significance when some disaster occurs. An example of a case where information was available but where its significance was not appreciated was illustrated when British Aerospace issued a Manufacturer's Operations Manual amendment to British Airways for the ATP in February 1991, which introduced information that control system damage could occur in wind speeds in excess of 52kts. However, on receipt of the letter of transmittal the significance of the information was not appreciated (partly due to the wording) and beyond incorporating the amendment no further action was taken. In December 1991 an ATP suffered damage to the right wing tip and aileron shortly after take-off following contact with the ground, the right aileron operating arm had been fractured resulting from the aircraft being taxied in wind conditions in excess of those in which the manufacturer advised damage to control surfaces or systems may occur.

It may be that flight deck workload distracts attention from emerging signs of danger; or, that crews distrust the source from which the information is coming; an example of this was discovered using BASIS and importantly interpreted as a possible accident precursor; ground proximity warnings that were not genuine were highlighted and investigation revealed that 82% of all warnings were either false or nuisance warnings, the investigations also revealed that there was a trend for crews to mistrust the warnings and in some cases, not take avoidance action in accordance with the company Standard Operating Procedures. Initially the Engineering department were only concerned with the warnings where equipment had mal-functioned, but as the potential problems were discussed in the context of the total operation, it was agreed that preventive action was required. Sundstrand Data Control Inc. were invited to collaborate on a project aimed at reducing this problem by a factor of 10.

Flight and ground crews can be "decoyed" by some aspect of a situation into a failure to perceive the emergent dangers of another aspect of the system; or, because they have difficulty in classifying a phenomenon and may mis-classify it and fail to act or act inappropriately; or, they may have difficulty in separating the information-giving event from the "noise" of other irrelevant information. This has been evident throughout the industry in many accidents where flight and ground crews have not realised the potential problem of one failure or warning, when

combined with another in a different system. In the case of information which is available but not in a usable form it is possible to identify any number of different information difficulties, for example, information may be available but hidden amongst other material, similarly warning information may not yield its significance without some sensitivity in the mechanism for assembling, filtering and interpreting it. BASIS has been successful in coding and separating information to reveal potential accident causal factors from within a large volume of incident data.

A further problem is that relevant information may be distributed between several organizations or parts of one organization and, hence, its significance may not be appreciated unless by some fortuitous act it is brought together in one person or situation. Similarly, there may be information difficulties associated with the interaction of two or more different systems, each of which when acting independently is safe but when brought into conjunction have inappropriate means for dealing with information at the interface between the separate systems. Other examples may arise in cases where, for instance, prior information is deliberately withheld. There may be a considerable range of behaviours and motives associated with the withholding of information including fear, malice, complacency but the point is that some information will be available within the incubation period but not emerge until after the system has failed.

British Airways Safety Services invited two non-operational staff to examine incident data to give an external perspective, they discovered that most air safety reports were generated when the aircraft was on the ground, with damage being highlighted, this problem was not previously appreciated partly due to non-centralised reporting. Investigations revealed that major damage occurred to an aircraft every 23 hours with a conservative estimated cost of $20 million per year. During the summer of 1992 a Boeing 757 had to return to London Heathrow due to a rupture in the fuselage following unreported damage caused by a ground vehicle. There are clearly air safety implications for ground incidents including damage to aircraft, even though this may not be the obvious category for reporting.

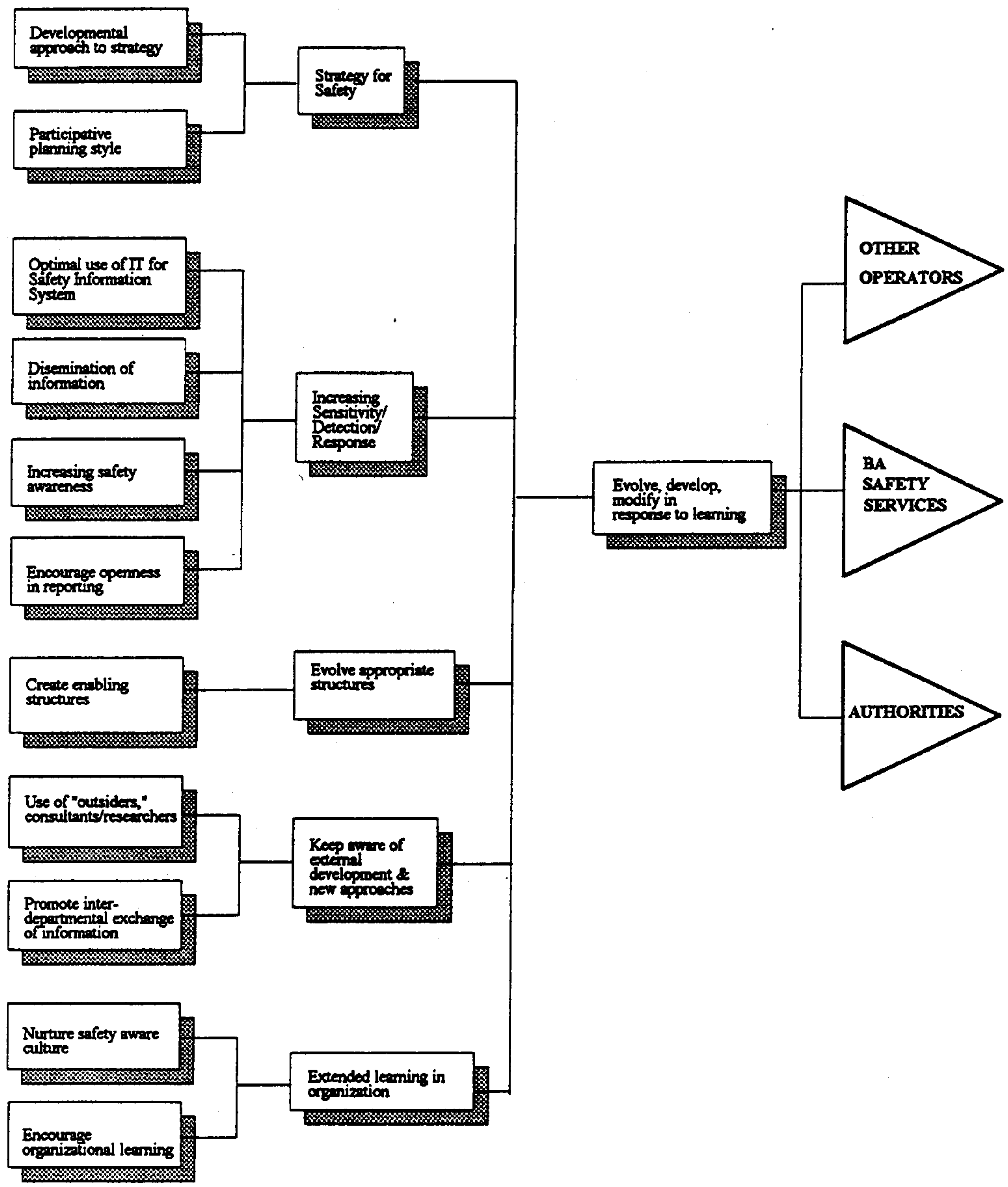
The issue of information for which there are no appropriate categories is an important one. Sometimes individuals are unaware of the extent of their ignorance about the system they are operating, particularly in its wider systems context. However, often it is the case that there is no appropriate channel for the specific or discrepant piece of information to enter the system either because the particular problem is not officially recognized as a hazard or because the existing construction of the situation does not permit the new information to disconcert perceptions. This latter point is significant in that perceptual rigidities may confine attention within an organization to specific ways of perceiving its task, to "bounded decision zones" (op.cit: 200). The problem for safety management is that it is what is left outside of this "bounded rationality" which is likely to be far more hazardous than those aspects of the system which have been anticipated.

This presents considerable difficulties. Clearly, some of the information difficulties discussed above can be dealt with by organizational responses and appropriate systems. However, some information difficulties are much more intricately enmeshed in the social fabric of the organization and resistant to exposure. Writing in 1987, Westrum has drawn attention to ways in which organizations can promote safer practices and has advocated what he terms a "generative" as opposed to a "calculative" rationality as a means of reducing organizational failure. Many of the features Westrum puts forward, implicitly feature in the way in which British Airways developed its new philosophy for safety management. For instance, Westrum argues that generative organizations should,

1. Encourage system-wide awareness on the part of all members of the system
2. Encourage creative and critical thought
3. Link interdependent parts of the system
4. Scan the different parts of the system for relevant solution to organizational problems, to be used regardless of their origins
5. Reward system-oriented patterns of thought
6. Avoid over structuring the organization
7. Examine mistakes honestly.

Westrum's message initiated a debate in safety management practices and it is within this context and as an extension of the debate that a concern to activate the generative features of safety management that issues in organizational learning have come into prominence. In British Airways, this concern has been seen in the way that Safety Services have constructed an Interpretative Environment around its safety information system.

The conceptional underpinning of Safety Services Blueprint for Safety (Wright, C and MacGregor, C 1990)

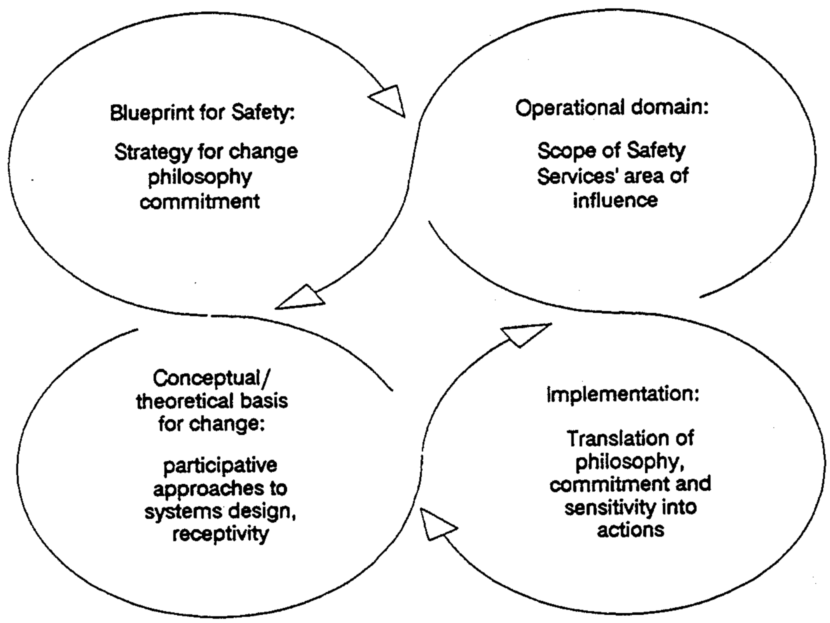


Based on Pedler, M et al 1991 (op.cit: p.25)

Figure 3

A significant part of this environment is rooted in a commitment to the principles of organizational learning. Fundamental to this is the development of a principle of double-loop learning which ties together the relationship between BASIS and its Interpretative Environment in a continuous flow (Pedler et al: p.32) of Policy, Operations, Action, Ideas, Policy and so on. An appreciation of this flow is important for understanding where blockages of information and slippage's may occur since these may cause stress within the system with pathological consequences as suggested by Reason's pathogen model.

The Energy flow in Double Loop Learning : creating an interpretative Environment for Safety



Based on Argyris, C and Schon DA, 1978 organisational learning L A Theory in Action Perspective, Addison-Wesley.

Figure 4

Recent work by Turner (1992) has focused on ways in which organizational learning can be considered in approaches to safety management and has drawn attention to the importance of getting behind appearances in order to gain access to organizational processes. In this respect, he argues that new organizational learning requires an appreciation of the processes and multiple perceptions of which organizations are made up; that the learning cycle is complicated by ambiguities, corruption of meaning, multiple meanings, symbols and so on; that the assumption of rationality needs to be bracketed: that records and computerized systems need to be regarded as problematic; that assumptions of completeness need to be challenged; that interpretative methods need to be used to get behind taken for granted assumptions.

In short, Safety Services have been seeking to use the principles of organizational learning in order to achieve the optimization of information capture and interpretation within a dynamic interpretative environment. The development of the British Airways Safety Information System is complemented by its interpretative environment in order to stimulate reciprocity between information which is comparatively straightforward to acquire and that which is not. This implies developing a sensitivity and responsiveness within the system to the complex, irrational, embedded, conflictual aspects of information which may be permitted to emerge by a commitment to organizational learning and the acquisition of a dynamic memory.

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ABSTRACT

"Inflight Medical Care - An Update"

C.A. DeJohn, S.J.H. Veronneau, and J.R. Hordinsky
Civil Aeromedical Institute
Oklahoma City, Oklahoma, USA

A survey of the status of inflight medical care was undertaken for the years 1990 to 1993. The information was reviewed to determine which category of inflight medical emergency occurred most frequently, and the categories which had the greatest probability of diverting. The impact of inflight medical advice was evaluated by comparing the number of diversions that resulted in hospital admissions to the number that did not.

Future research should focus on the relationship between the diversion rates and the categories of emergencies, the cost of diversions, and improvements in the appropriateness of medical judgment.

To adequately evaluate inflight medical care industry-wide, data on the frequency and categories of emergencies, diversions, and outcomes following hospitalization or treatment, needs to be collected in a standardized format.

Conclusions from the 5 year Research Programme on the M1 (Kegworth) Aircrash

Professor W Angus Wallace* FRCSEd, FRCSEd(Orth)
Mr Peter Brownson* DM, FRCSEd, Mr Raf Haidar# BSc, PhD
Mr John M Rowles* DM, FRCS and Mr David J Anton+ MFOM DAvMed RAF

*Department of Orthopaedic & Accident Surgery, University Hospital
Queen's Medical Centre, Nottingham NG7 2UH

#Department of Mechanical Engineering, University of Nottingham NG7 2RD
(Previously Hawtal Whiting Engineering, Leamington Spa, Coventry)

+Anton Associates, The Barn, Water St, Barrington, Nr Ilminster, Somerset TA19 0JR
(Previously Biomechanics Division, RAF Institute of Aviation Medicine, Farnborough, UK)

Abstract

The NLDB Research Team have learned much about the safest position to adopt at the time of a front impact aircraft accident both through deceleration track testing and through computer modelling. The Civil Aviation Authority (CAA) in the UK has taken advantage of our research findings and have changed the safety guidance to passengers both in relation to the Safety Card and the Safety Announcement at the beginning of each flight for all UK based airlines. By adopting only one standard "Brace for Impact" position passengers are now fully aware of what they should do in the event of an emergency. Approximately one third of European carriers have also adopted our "Brace for Impact" position but regrettably North American Carriers have made almost no changes because the Federal Aviation Authority (FAA) is still considering our research findings. Now that we have confirmed through further testing that the Nottingham "Brace for Impact" position is safer than all the others we have researched we look forward to the FAA also adopting this as their preferred position.

Introduction

Following the M1 (Kegworth) Aircraft accident on 8th January 1989 a multi-disciplinary research group was set up (Wallace, 1989) with the support and approval of the Civil Aviation Authority (CAA). The Research Group was ultimately called the NLDB study group - named after the four cities associated with the accident - Nottingham, Leicester and Derby in the Midlands of England where the accident survivors were looked after and

Belfast in Northern Ireland - the city to which the aeroplane was flying and to which many of the passengers belonged.

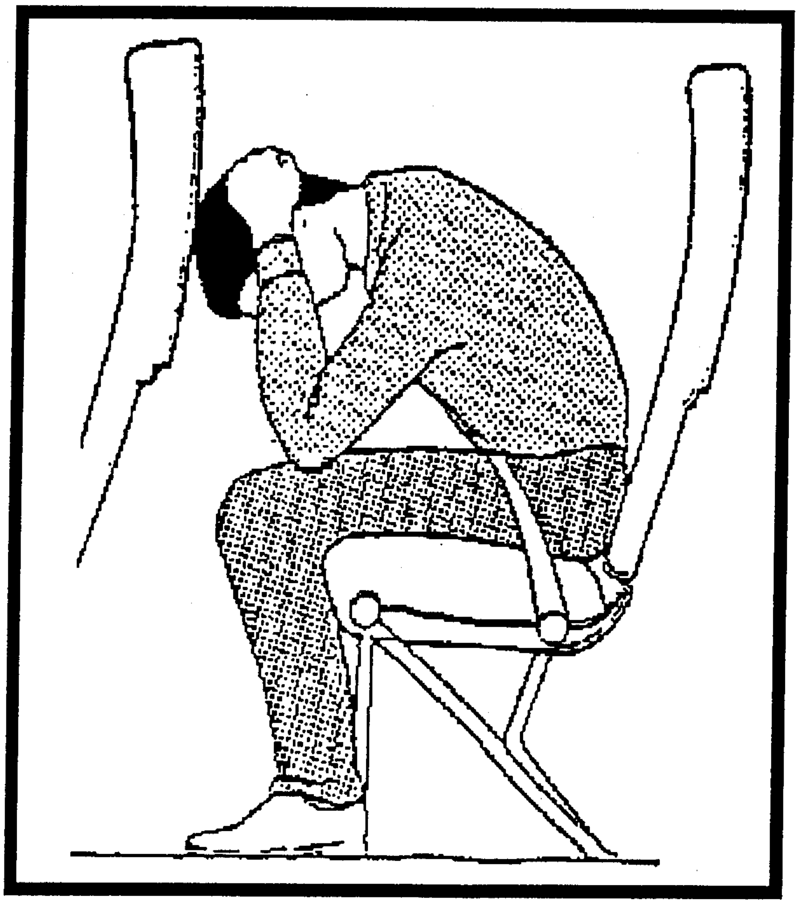
On 15th October 1990 the NLDB study group published their first report - "NLDB Report on the M1 Aircraft Accident" and the recommendations from that first report are listed below.

The Findings and Recommendations of the NLDB Study Group

Recommendations concerning aircraft design

1.1 The braced crash position protects against injury and should be demonstrated prior to every flight. This is much more relevant than the routine demonstration of life jackets. The braced position that affords best protection against injuries is shown in Figure 1 (below)

Figure 1. Recommended brace crash position



Adopt a crouched position like a ball. Hands clasped firmly on top of head. Elbows tucked outside knees. Head resting against the structure in front if possible. Legs should be positioned with feet together slightly behind knee.

1.2 The occupant environment within the aircraft should be improved. Particular attention should be paid to making the rear of seats more impact friendly, in order to reduce the risk of injury to the occupant by impact with the seat in front.

1.3 Overhead bins should either be more securely fixed or they should be eliminated. The contents of the bins should be limited and bin door design improved.

1.4 Rear facing seats would decrease injuries. However in the presence of flying debris there may be an increased risk of the face and head being struck unless overhead bin design is improved. Further research on rear facing seats is strongly recommended.

1.5 The floors of modern aircraft should be strengthened to withstand the dynamic forces experienced in a crash.

Progress with the NLDB Recommendations - 1990 to 1995

1.1 The Nottingham "Brace for Impact" position has been intensively researched initially under the supervision of Wing Commander David Anton at the Royal Aircraft Establishment, Farnborough. John Rowles (an orthopaedic research registrar) - carried out the initial deceleration crash testing, Peter Brownson (his successor) later carried out more intensive deceleration track testing and Raf Haidar (an engineer) and Nigel Rock working at Hawtal Whiting, completed the Madymo computer simulations of the impact accident scenarios. John Rowles and Peter Brownson have now both been awarded Doctorates in Medicine(DM) for their research in 1993 and 1994, while Raf Haidar will be awarded his Doctorate in Philosophy(PhD) in early 1996. The ground work by John Rowles identified the Nottingham "Brace for Impact" position as being that position most likely to result in the lowest risk of injury. However using the Hybrid III anthropomorphic dummy (ATD) on the deceleration track Brownson identified higher loads in the lumbar spine and possibly higher loads in the cervical spine when the dummy was placed in the "Brace for Impact" position. Because of this finding, further research work was required using the Madymo computer simulations - work which was supported by the CAA and carried out by Haidar and Rock. By July 1995 this work had been completed and confirmed the early findings that the "Brace for Impact" position initially described by the NLDB team was the best and safest position to adopt and the forces in the lumbar and cervical spines were not adversely affected when this position was adopted. As a result the CAA have issued further advice to UK based airlines that all passengers should adopt the Nottingham "Brace for Impact" position in the event of a crash and all Safety Cards on aircraft now carry pictures of this position. Our

findings have also influenced many European and some Far East airlines. Initially North America appeared to ignore our trans-atlantic research but very recently there has been significant interest in our findings. The Federal Aviation Authority have been provided with detailed information about our research programme but to date have taken no action as a result of our findings.

1.2 We are not aware of any specific efforts by aircraft seat manufacturers to make the rear of seats more impact friendly. In fact the introduction of solid state video screens into seat backs would appear to be exactly the reverse. However in the event of a front impact accident the head of the passenger sitting behind such a video screen would normally contact the bottom half of the seat back i.e. below the video screen. This is likely to be further investigated through the "Occupant Crash Protection" programme - JAA/(3) (see FAA/TCA/JAA, 1995).

1.3 The NLDB study group were satisfied, from their analysis of the injuries, that a number of passengers had received head injuries as a direct consequence of the overhead bins becoming detached. The response of aircraft overhead stowage bins under dynamic stress is now under investigation - JAA/(3) and FAA(TC)/4 (see FAA/TCA/JAA, 1995). We believe Boeing are reviewing the strength of the overhead bins. Cabin stowage compartment latch integrity is currently being investigated - TCA/(5) (see FAA/TCA/JAA, 1995). In addition, a survey of overhead bin loading is also underway - JAA(CAA)/(3).

1.4 Regrettably we know of little if any action which has been taken on progressing further research into rear facing seats. Despite over 5 years of work carried out in Nottingham University, the Royal Aircraft Establishment in Farnborough and at Hawtal Whiting in Leamington Spa, which has regularly demonstrated that for a passenger with a lap style seat belt rear facing is better at protecting from injury than forward seated passengers, the aviation industry is resistant to considering this re-arrangement of seating.

1.5 We believe aircraft floor specifications are being reviewed and new aircraft are likely to be fitted with stronger floors in the future - JAA/(3) (see FAA/TCA/JAA, 1995).

Acknowledgements

We would like to thank Mr Nigel Rock for his significant support to the research programme. At Farnborough, Mr L Neil and Mr G Hall provided invaluable practical help and Surgeon Commander P Waugh provided considerable help with data acquisition. We are grateful to both the Medical Research Council (UK) and the Civil Aviation Authority who have funded parts of the research programme.

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Managing in flight emergencies

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Earlier this year the dramatic story of a makeshift operation aboard an aircraft flying from Hong Kong to London hit Britain's newspapers. Here the surgeon who performed the in flight operation gives an account of what happened, and he and the other doctors who treated the patient assess the problems of managing medical emergencies in the air.

A Personal Account

Professor W Angus Wallace FRCSEd, FRCSEd(Orth)
Department of Orthopaedic & Accident Surgery, University Hospital
Queen's Medical Centre, Nottingham NG7 2UH

I was on board a Boeing 747 bound from Hong Kong to London and was seating myself before departure when a call was made by the stewardess: "If there is a doctor on board would they please make themselves known to the cabin staff." I offered assistance. A 39 year old woman in the back row of economy class had become concerned about the swelling developing in her forearm which another doctor, Dr Tom Wong, was examining as I joined him. She told us that she had fallen off a motorcycle on the way to the airport. She had been shaken by the accident and had missed her original flight before catching this one. The problem appeared to be bruising and a probably minimally displaced fracture of the right forearm. She did not complain of any other injuries, and though I had attended an advanced trauma and life support course in 1990, I did not carry out a full primary survey - there seemed to be no need, and it might have been misunderstood by the patient.

I decided that the forearm injury could be managed satisfactorily on board. I recommended that in the first instance the arm should be raised on a pillow and that more formal splinting could wait until after take off, to avoid any delay to the flight.

After take off, when the seat belt signs had been switched off, Dr Wong and I splinted the arm. Samsplint - a flexible aluminium and rubber based splinting material, a bandage, and a sling were all available in the plane's M5 medical emergency kit. A Hong Kong newspaper was used as additional padding. The splint was effective, the arm was elevated, and the passenger felt comfortable. I then completed a medical report with the air stewardess. All seemed well and we returned to our seats to enjoy our first meal on board.

The first signs of real trouble

About 45 minutes later (more than an hour into the flight) I was told that the passenger had developed left sided chest pain, which she had noticed when she had bent down to remove her shoes. Examination confirmed tenderness of the lower left ribs with probably fractures of between two and four ribs.

An injectable painkiller was indicated for the rib fracture pain and this was sought from the emergency kit. The kit was well supplied with drugs and also included a guide on their recommended dosages. An injection of nalbuphine was prepared, but when I returned to the patient she was obviously ill. The injection was not given, and I re-examined her. She was in respiratory distress with mild tachypnoea. Chest percussion and auscultation could not be carried out effectively because of the engine noise but her trachea was significantly deviated to the right. I realised there was a serious problem and asked Dr Wong for a second opinion. He agreed with the findings and an oxygen mask was immediately applied.

I then visited the flight deck and explained to the captain that the patient had a tension pneumothorax and asked if medical advice could be obtained from the ground, particularly advice on the available surgical equipment. It was not possible to receive immediate advice and I decided to proceed with surgery.

In flight surgery

The aircraft's medical kit had a scalpel, sharp pointed scissors, and a 14 gauge urinary catheter. Xylocard (100mg of lignocaine in 5 ml) was available for use as a local anaesthetic, but in the heat of the moment, neither I nor Dr Wong were able to calculate the percentage of lignocaine in it.

There the routine equipment ended; we prepared heated hand towels for sterile drapes, a modified coathanger as a trocar for the urinary catheter, a bottle of Evian water with two holes created in its cap for use as an underwater seal drain, and a length of oxygen tubing to attach the catheter to the drain. In addition Sellotape was used to anchor the catheter to the oxygen tubing and five star brandy as a disinfectant for the introducer.

I advised the patient that she had a serious condition and that an operation was required, but she was too ill to give written consent. With the patient seated in her aircraft seat, the operation - the insertion of a chest drain under local anaesthetic - was performed. I planned to insert the chest drain into the left second intercostal space in the mid-clavicular line because this was the most accessible area and would control a tension pneumothorax. As soon as the drain was connected, air was released from the pleural cavity and within five

minutes the patient had almost fully recovered. The patient was left sitting in her passenger seat and settled down to enjoy her meal and the inflight entertainment.

I then had to prepare a full medical report for the second time, a task made difficult by the changing time zones. The air stewardess thought that we should document all the times in British Summer Time and this proved to be the best decision.

The patient was now comfortable, felt well and we retired to our seats to recover. Eight hours later I was again summoned by the stewardess to see the patient, who had developed more chest pain and dyspnoea.

I found her sitting on the toilet with the underwater seal drain on a high shelf. All the water and air had syphoned out of the bottle into the chest. The crisis resolved when I placed the underwater seal drain on the floor - draining the water back from the chest to the bottle. The air bubbled out of her chest when she coughed. After a few minutes she was almost back to normal, but exhaustion precluded the completion of a third full medical report.

Back on land

On arrival at Heathrow she was transferred from the aircraft by British Airways ambulance to Ashford Hospital. She was still mildly short of breath and complaining of discomfort over the left chest wall. Examination showed clinical evidence of a fracture of the left sixth rib in the mid-axillary line. A full blood count and arterial blood gases were normal. A chest radiograph revealed a 30% residual left sided pneumothorax; and our temporary drainage catheter had been inserted in the third intercostal space and was still in place.

She was given parenteral analgesia, intravenous antibiotics, and tetanus prophylaxis. The Foley catheter was removed and a 28 Fr chest drain was placed under local anaesthetic. A Repeat radiograph showed complete lung expansion, and subsequent recovery in hospital was uneventful.

Discussion

Professor W Angus Wallace* FRCSEd, FRCSEd(Orth)
Dr Tom Wong+ MB, ChB
Mr Austin O'Bichere FRCS and Mr Brian W Ellis FRCS#

*Department of Orthopaedic & Accident Surgery, University Hospital
Queen's Medical Centre, Nottingham NG7 2UH
+ Medical Senior House Officer, Stracathro Hospital, Brechin, Angus DD9 7QA
#Department of Surgery, Ashford Hospital NHS Trust, Ashford, Middlesex TW15 3AA

Meticulous screening and preparation of air travellers with known ailments would prevent most in flight emergencies if passengers at risk sought a medical opinion about their suitability for travel.[1] In the absence of declared symptoms, however, the prediction of a potentially fatal condition at altitude is difficult if not impossible in a young patient apparently fit to fly. A useful review of the particular medical risks to be considered before travel by air is provided by Skjenna.[1]

Medical emergencies among airline passengers and staff during flight are not common: serious in flight events occur once in every 753 flights (about 1 per 40,000 passengers).[2] In 1994 British Airways health services logged all 2078 medical incidents occurring on British Airways flights, ranging from headache to myocardial infarct. Most of these were dealt with by cabin staff without calling for help from a doctor or nurse on board. In 559 cases help was given by a doctor or nurse responding to such a call; 18 flights were diverted to allow a critically ill passenger to be treated at the nearest possible hospital.

Conditions on board

The conditions in the cabin of a commercial aircraft are less than ideal for assessing and managing any acute medical condition; this is especially true of a pneumothorax. At cruising altitude the cabin pressure is maintained at the equivalent of that at about 2500 metres (7000 feet); at this pressure the partial pressure of oxygen will fall in the normal adult to about 8·64 Kea. While this is still on the flat part of the oxygen dissociation curve for normal subjects it can represent a severe embarrassment to anyone with a cardiopulmonary problem giving rise to any appreciable degree of pulmonary shunting. Furthermore, the diminished pressure will lead to expansion of gas by about 30%, which if constrained within a cavity such as the thorax, will inevitably aggravate a pneumothorax.

An aircraft cabin is a particularly noisy environment. There is an excess of low frequency (<4000 Hertz) noise at sound pressure levels of about 65 dB; in some less refined aircraft it

may be as much as 90 dB. With this degree of background noise a stethoscope is virtually useless.[3] It has been suggested that the best use for a stethoscope in flight is that it acts as a symbol by which the doctor can be identified.

The very nature of commercial airline travel is such that the nearest fully equipped medical facility is only as close as the hospital serving the airport of destination unless a patient's condition is deemed so critical as to warrant diversion - a disruptive event for every other passenger and a costly one for the airline. In this case the acute event occurred only one hour into a 14 hour non-stop flight from Hong Kong to London. The rapid increase in dyspnoea in this case indicates that diversion may not have been sufficiently rapid to prevent a fatal increase in intrathoracic pressure.

Promise of telemedicine

The carrier in this case (British Airways) is due to install telemedical links from its long haul flights to relay "vital signs" to physicians on the ground who can provide advice and support to the cabin crew and any doctors on board. Sensors from a monitoring unit are attached to the passenger. The unit is connected to the aircraft's satellite communication system through a socket in the arm rest of the passenger's seat. On the ground the signals are transmitted to the duty doctor wherever he or she is via a briefcase sized laptop computer. In this particular case, however, such equipment probably would not have helped.

The emergency medical kit provided by British Airways includes 88 items and is suitable for most medical emergencies - with an emphasis on cardiac drugs and delivering babies[4]. Unfortunately, its surgical equipment is pretty sparse. This is justifiable as most people suffering a surgical emergency do not come to harm if treatment is delayed for one or two hours. A suitable local anaesthetic would, however, have been a helpful addition. This has now been addressed by the providers of the M5 medical emergency kit, and a 20ml multidose vial of lignocaine 2% will be included in future (personal communication, Aeromedic Innovations, London).

Traumatic pneumothorax has not previously been reported as presenting during a commercial flight. Several cases are on record of patients with such a condition being evacuated by air after receiving treatment for their thoracic trauma in conditions of warfare or civil disobedience.[5] Survival is good as long as thoracic drainage is established before flight.[6]

This case shows the need for doctors to be adaptable to work in very strange environments dealing with conditions they do not normally treat and with unfamiliar equipment.

Innovation in the use of the materials to hand to enable adequate chest drainage may well have saved the patient's life.

Acknowledgements

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Training & Equipment for In-flight Medical emergencies

Professor W Angus Wallace* FRCSEd, FRCSEd(Orth)
Mr Frank Coffey# MRCP(I), FRCSEd(A&E)
*Departments of Orthopaedic & Accident Surgery and #Accident & Emergency Medicine, University Hospital, Queen's Medical Centre, Nottingham NG7 2UH

INTRODUCTION

Before the 2nd World War most major US airline companies required applicants for the position of stewardess to be graduate nurses because the companies had recognised that this was one of the best ways of ensuring the availability of first-aid treatment on board commercial airlines for passengers who became ill in-flight[1]. However during the war, because nurses were required to attend to the injured troops, this requirement was waived and has not been re-instituted.

The personal experience of one of the authors (WAW) of the ability of cabin crew to carry out an early assessment of medical problems and provide appropriate first-aid during international flights has now been significant.

> " I have been disappointed to be present at a number of incidents where a person became unwell and this was not spotted early. I first experienced this in 1991. My wife and I provided emergency medical care for a passenger with angina and heart failure after open heart surgery who was returning from London to Cairo. The Egyptair cabin crew appeared to have no knowledge of first aid, no medical equipment or first-aid box appeared to be available and even the oxygen cylinders were either empty or could not be connected to the oxygen masks! In 1994, I travelled to Spain in a leg cast after an injury. The cabin staff on the Iberian Airlines plane had no idea about the importance of elevating a limb that was in a cast while flying. In September 1995 one of the passengers on a Sabena Belgian World Airlines flight became obviously ill and was drifting into a diabetic hypoglycaemic coma. The Sabena cabin staff did not realise the passenger was ill and offered no assistance whatsoever. Fortunately the passenger knew what the problem was and treated himself before he became unconscious."

THE PRESENT SITUATION IN EUROPE & NORTH AMERICA

We have surveyed the Airlines in Europe(Appendix 1) and in North America (Appendix 2)

in early October 1995 to find out the current state of first-aid training for cabin staff. As the FAA have introduced regulations regarding an enhanced medical kit in 1986 (Cottrell et al, 1989) we did not include questions relating to this in the North American Questionnaire as we assumed that North American airlines would naturally conform to the FAA regulations. However we were interested in the provision of medical kits in European aircraft and this was included in the European questionnaire.

The questionnaires were distributed by FAX in early October 1995 using International Fax Numbers provided in "Flight International" World Airlines Directory 22-28 March 1995 (Part I - The Americas) and 29 March - 4 April 1995 (Part 2 - Europe). Responses were requested by 31st October 1995.

RESULTS FROM THE QUESTIONNAIRE

The European Airlines contacted and those who responded are listed in Appendix 3. The North American Airlines contacted and those who responded are listed in Appendix 4. The response rates for European airlines was 27/85 (32%) and for North American airlines was 9/52 (17%) . We recognise however that the airlines were only given 3 weeks to respond and this may, in part, explain the poor response rates. However as some airlines (for instance Swissair) were able to respond within 48 hours, it is the authors' view that if First Aid in the air was felt to be a high priority by airlines then there would have been a much higher response rate.

One of the questions which is clearly in the minds of airlines is whether "intelligent" cardiac defibrillators should be carried by long haul aircraft. The introduction of defibrillators by Dr PJC Chapman and Dr Douglas Chamberlain onto British Caledonian aircraft was innovative and subsequently Dr Mike O'Rourke and Dr Donaldson followed suit with Qantas. More recently Chamberlain has provided advice to Virgin Atlantic Airways and currently **all** Virgin Atlantic planes carry defibrillators (Chamberlain, 1995). There is accumulating evidence that some lives will be saved with the use of cardiac defibrillators on board **BUT** this will only occur if there is systematic and appropriate staff training in cardiac resuscitation using such equipment. Currently, the cost/benefit equation, in the eyes of the airlines, does not yet justify the widespread introduction of such equipment.

The conclusions we have reached from the responses to the survey are:-

- Cabin Staff are genuinely interested in providing First Aid
- First Aid training is at a very basic level and in some cases clearly inadequate
- In Europe there is no uniformity in what is carried on board in the Medical Kit

- In North America some airlines have experienced a real problem obtaining help in an emergency from a doctor but have obtained good support from nurses and paramedics
- The stocks of drugs and medical treatment equipment in North American airlines is very significantly poorer than for the majority of airlines in Europe
- The M5 medical emergency kit, produced by Aeromedic Innovations in London for British Airways appears to be one of the most comprehensive and carefully planned in-flight medical kits
- The North American airlines seem reluctant to provide better Emergency care for fear of becoming involved in litigation
- There remains a major question about whether "intelligent" cardiac defibrillators should be available on long haul flights
- There is considerable scope for improvements to be made

RATIONALISATION OF THE MEDICAL KITS ON BOARD

The Emergency Medical Kit is, of course, vital in these situations and I have reviewed some of the literature over the last five years which has focused on this area (see bibliography). In general doctors are insecure when out of their hospital environment - even more so when they have no idea what medical equipment is available to them. I believe that if there were an international standard "Emergency Medical (or Doctor's) Kit" and "First-Aid Kit" **and** information on its contents were more readily available to doctors, then more doctors would volunteer to help in emergency situations. I am concerned about the attitude of a number of doctors mainly from North America but also some from Europe who:-

a) Purposely conceal the fact that they are MDs when flying
b) Do not respond to a call for a doctor to provide emergency medical treatment
c) Are so worried about litigation that they feel unable to provide help when requested

In France it is illegal to ignore a person in need of medical treatment (Learmount and Thompson, 1995). There is clearly a case in North America for the revision of the "Good Samaritan" law which will protect doctors who offer help and do the best they can. Although a "Good Samaritan" law was passed in the US in 1985 to protect ordinary citizens who offered in-flight first aid it was regrettable that it was only possible to obtain approval for that legislation by excluding both the commercial airline and doctors from that "Good Samaritan" law on the grounds that both must have insurance cover. In fact very few British doctors have medical insurance cover for providing any medical treatment when they travel in the US and are therefore in an even less enviable position than American doctors!!

As a result of the media cover relating to "Operation Coathanger", a number of doctors have approached me about their own experiences with on-board emergencies, and I have learned much from these. I am now in a position to review the problems that I personally experienced in suddenly being asked to provide medical help in an emergency. However before doing so I would like to review the situation regarding the provision of first aid treatment outside the aircraft industry - for instance in factories, shops, offices and universities in the UK.

FIRST AID AVAILABILITY IN THE WORKPLACE IN THE U.K.

The Regulations for the provision of First Aid is laid down in "First Aid at Work - Health and Safety (First-Aid Regulations) updated in 1990. Employers are required to provide, for their employees in the workplace (offices, shops, factories, universities etc) the following:-

- First-aid training to ensure that some employees in the workplace are "first-aiders"
- "First-aiders" should hold a current first-aid certificate (valid for 3 years)
- To obtain a first-aid certificate it is necessary to attend a training course of at least 4 days and pass an examination(see later)
- Refresher courses lasting at least 2 days are necessary after 3 years and again the person has to pass a further examination
- One trained first-aider is required for every 50 employees in the workplace
- A first-aid kit or box suitably equipped must be provided in the workplace

Approval of first-aid training and qualifications

The syllabus for first aid training should include the following subjects:-

- resuscitation
- treatment and control of bleeding
- treatment of shock
- management of the unconscious casualty
- contents of first-aid boxes and their use
- purchasing first-aid supplies
- transport of casualties
- recognition of illness
- treatment of injuries to bones, muscles and joints
- treatment of minor injuries
- treatment of burns and scalds
- eye irrigation
- poisons

- simple record keeping
- personal hygiene in treating wounds with special reference to Hepatitis B and HIV
- communication and delegation in an emergency

Suitable arrangements are required at the end of the courses for conducting examinations which should be carried out by independent examiners.

THE FUTURE

It is my hope that as a result of this study we might see a dramatic change in attitudes both to the early introduction of an International "Emergency Medical (or Doctor's) Kit" and an International "First Aid Kit" which should be of a significantly higher standard than that currently recommended by the FAA. A survey of North American Airlines is currently planned (but not yet underway) by the FAA - FAA(CAMI) (see FAA/TCA/JAA, 1995). We also hope that the US administration in particular will make it easier for doctors who fly to provide emergency medical aid without the fear of litigation by altering their legislation to include doctors under the "Good Samaritan" regulations

If that happens then I believe the success of this meeting will have been on a par with the successful outcome from the medical management of Paula Dixon on the flight from Hong Kong to London on 20th May 1995.

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APPENDIX 1

Questionnaire to all European Airlines
Staff training in medical emergencies and on-board medical kits

1) What training in First Aid and Resuscitation do **all** your fully trained cabin staff undergo?

2) How often do they undertake refresher courses in First Aid and Resuscitation?

3) Are your staff assessed or given a practical examination in First Aid &/or Resuscitation?

4) If yes, what happens if they fail this assessment or practical examination?

5) Do all your aircraft carry a First Aid Kit?

6) If No, do any of your aircraft carry a First Aid Kit?

7) What are the contents of the First Aid Kit? Please provide a list.

8) Do all your aircraft carry an Emergency Medical Kit?

9) If No, do any of your aircraft carry an Emergency Medical Kit?

10) What are the contents of the Emergency Medical Kit? Please provide a list.

11) Do you have a problem getting:- a) Doctors
b) Nurses
c) Paramedics
to come forward if you have a Medical Emergency on-board?

12) Have you taken any action to improve the provision for medical emergencies on-board during the past 5 years? If Yes, what action has been taken?

13) Do you have any plans to improve the provision for medical emergencies on-board during the next 2 years?

APPENDIX 2

Questionnaire to all North American Airlines
Staff training in medical emergencies and on-board medical kits

1) What training in First Aid and Resuscitation do **all** your fully trained cabin staff undergo?

2) How often do they undertake refresher courses in First Aid and Resuscitation?

3) Are your staff assessed or given a practical examination in First Aid &/or Resuscitation?

4) If yes, what happens if they fail this assessment or practical examination?

5) Do you have a problem getting:- a) Doctors
b) Nurses
c) Paramedics
to come forward if you have a Medical Emergency on-board?

6) Have you taken any action to improve the provision for medical emergencies on-board during the past 5 years? If Yes, what action has been taken?

7) Do you have any plans to improve the provision for medical emergencies on-board during the next 2 years?

APPENDIX 3

The European Airlines contacted and those who responded

Name of Airline	RESPONSE +ve	RESPONSE Date	Name of Airline	RESPONSE +ve	RESPONSE Date
Aer Lingus	✔	22/11/95	Brit Air		
Aero-Lloyd Flugreisen GMBA & Co			Britannia Airways	✔	25/10/95
Air 2000			British Airways	✔	19/10/95
Air Belgium			British International Helicopters		
Air Berlin			British Mediterranean Airways	✔	27/10/95
Air Bristol	✔	30/10/95	British Midland	✔	23/10/95
Air Europa			Cimber Air Denmark	✔	26/10/95
Air France			City Air Scandinavia		
Air Holland Charter BV			Compagnie Corse Mediterranee		
Air Intger			Condor Flugdienst	✔	30/10/95
Air Malta	✔	31/10/95	Corsair International	✔	25/10/95
Air Provence International			Croatia Airlines		
Air Saint Pierre			Crossair		
Air UK Leisure			Cyprus Airways		
Air UK			Eurocypria Airlines	✔	31/10/95
Air Volga			Eurofly		
Airtours International	✔	23/10/95	European Air Transport		
Armenian Airlines			European Airlines		
Atlantic Air Transport			European Aviation Air Charter		
Atlantic Airways			Excalibur Airways		
Austrian Airlines			Falcon Aviation	✔	18/10/95
Avia Express Airlines			Farner Air Transport		
Avia Nova			Finnair	✔	7/11/95
Aviaco			Futura		
Aviation Enterprise Pulkovo			GB Airways		
Belvavia Airlines			Germani Flugge Sellschaft		
Braathens Safe			Hamburg Airlines		

Name of Airline	RESPONSE +ve	RESPONSE Date	Name of Airline	RESPONSE +ve	RESPONSE Date
Iberia			Oasis International Airlines		
Icelandair	✔	13/11/95	Olympic Aviation		
Interot Airways			Olympic Airways	✔	31/10/95
Istanbul Airline			Pegasus Airlines		
Jaro International			Petersburg		
Jersey European Airways	✔	19/10/95	Polish Airways		
KLM City Hopper			Regional Airlines		
KLM			Romavia Romanian Airlines		
Knight Air			Russian International Airlines		
Lauda Air Luftfahrt AG			Ryanair		
Lietuva Air Company			Sabre Airways		
Lithuanian Airlines			Sky Service		
LOT Polish Airlines	✔	23/10/95	Sobelair		
LTE International Airlines			Spanair		
LTU International Airlines	✔	17/10/95	Sun-air of Scandinavia		
Lufthansa German Airlines			Swedair		
Lufthansa Cityline			Swissair	✔	13/10/95
Maersk Air			TAT European Airlines		
Malev Hungarian Airlines			TEA Basel	✔	25/10/95
Malmö Aviation	✔	1/11/95	Topair		
Manx Airlines			Tramsavia Airlines		
Martinair, Holland			Tyrolean Airways		
Monarch Airlines	✔	17/10/95	Virgin Atlantic Airways	✔	26/10/95
MUK Air			Volga-DNEPR Airlines	✔	3/11/95
Nordic East Airways	✔	30/10/95	Zimex Aviation		
Northwest Air Department/ST					

APPENDIX 4
The North American Airlines contacted and those who responded

Name of Airline	RESPONSE +ve	RESPONSE Date	Name of Airline	RESPONSE +ve	RESPONSE Date
Air BC			Canadian Regional Airlines	✔	16/10/95
Air Canada			Carnival Airlines		
Air Creebec			CC Air	✔	26/10/95
Air Inuit			Chautaugua Airlines		
Air Jamaica			Chicago Express Airlines		
Air Manitoba			COMAIR	✔	6/11/95
Air Midwest			Continental Airlines		
Air Nevada			Crown Airways		
Air North			Delta Airlines		
Air Nova			Evergreen International Express		
Air Ontaario			Express Airlines		
Air Vegas			Great Lakes Aviation		
Alaska Airlines	✔	20/10/95	Harbour Air		
Alpha Aviation			Helijet Airways		
American Airlines	✔	30/10/95	Horizone Air Industries		
America West Airlines			Kelowna Flight Craft		
American Eagle	✔	30/10/95	Key Airlines		
American International Airlines			Laker Airways		
American Transair			Liberty Airlines		
Athabaska Airways			Mesa Airlines		
Atlantic Coast Airlines			Miami Air International	✔	20/10/95
Basler Airlines			Millardair		
Bering Air			Norontair		
Business Express			North American Airlines		
Canada 300 airlines			North West Airlines	✔	30/10/95
Canadian Airlines International	✔	30/10/95	Peninsula Airways		

CRASH DYNAMICS SESSION

Wednesday, November 15, 1995

Session Chairman
Cliff Barrow
U.K. Civil Aviation Authority
Safety Regulation Group

AIR CRASH PROTECTION- A SYSTEM APPROACH

by

M. M. Sadeghi, Cranfield Impact Centre Ltd.,
Wharley End, Cranfield, Bedford, MK43 0JR, England.

ABSTRACT.

This paper proposes a procedure for carrying out crashworthiness analysis and design aimed at facilitating timely recommendations for crash protection. The process, which is a hybrid of accident investigation and computer simulation, is made very effective by developing simple simulation codes supported by the data bases of aircraft types, accident scenarios and human tolerance loads.

INTRODUCTION.

Due to the high level of publicity given to various road vehicle crashes, public awareness of transport safety has increased greatly over recent years. This, in part, has made crash safety a saleable product within the motor industry. The frequency of such accidents, in conjunction with published research into crash protection, has enabled the public to understand safety concepts. Thus, their perception of crash protection, in the case of passenger car, generally corresponds to reality. As a result of this awareness, a significant level of safety incorporated in to passenger cars is consumer driven. As the industry devises more economical means of meeting consumer demand for safety, the legislature sets new standards to ensure improved safety (Fig.1). This process has come to result in a logical, pro-active approach to vehicle safety which can be distinguished from simple reaction to individual accidents and emotive reporting. Although major accidents may be important news items, these should not become of over significance when considering recommendations for safety. In the case of air transport, where the number of crashes are small and there is relatively little published on research into safety, the public understanding of crash safety is limited and often based on sensationalised reporting of one or two crashes. Under such circumstances, the pressure of rapidly reacting to a crash can encourage conclusions which may not have been analysed to a satisfactory detail. It is therefore necessary to set in motion a process by which various possible crash type scenarios can be assessed and appropriate protective measures put forward and activated.

To ensure the effective operation of the pro-active process (which consists of public education improved understanding of safety concepts, industry's readiness to apply new safety standards, and legislating for such standards), it is necessary to consider safety as a system incorporating a number of inter related parameters. An assessment of various crash scenarios will aid an adequate definition of the required safety system. Such assessment include a clear understanding of the primary and secondary safety function of each structural component, as well as categorising the various perceived safety features as essential, highly desirable, desirable, and not required.

CRASH ENERGY DISTRIBUTION.

The use of crash tests, whether involving complete vehicles or sub-structures, generally does not provide complete information on true load paths. Such tests are devised to reproduce a pre-defined load and load path. The rationale behind these tests can be varied and although any design based on such tests will result in improved crashworthiness in a specific area, the test may not provide sufficient information on the effect of the improved component on the overall safety performance of the vehicle. For instance, various seat/restraint systems have been designed which attempts to minimise energy transfer to the occupant during a crash. In the case of such concepts, it has been shown that the forces generated at the seat /floor joint can often be incompatible with those designed for within the floor. The forces generated at the track from a seat incorporating a three point seat belt may exceed the load carrying capability of the

track. However, if there is sufficient information on the likely induced force during a survivable crash and the strength which can be designed into the floor supporting the track, a seat incorporating a three point belt can be designed for the aircraft. This "systems approach" will ensure that the seat/restraint package is not excessively strong and that restraint force on the occupant will be below human tolerance loads. As has been shown by past research into seat design, a seat structure can be developed that under crash deceleration it will collapse within a pre-defined stroke as well as a pre-defined collapse mechanism. Such development has the double effect of reducing the peak induced loads on the occupant as well as reducing the load generated at the track/seat connections. Fig.2 shows the result of incorporating 20mm of collapse within a seat's front legs with regard to the occupant's head acceleration, when the seat is subjected to a triangular 12g deceleration.

The most effective way to obtain an understanding of load levels and load paths through an aircraft during an air crash is by the combined effort of forensic accident investigation and mathematical modelling. Past experience has indicated difficulties in using either crash investigation or mathematical modelling on their own to understand the relationship between cause and effect within the various aspects of a crash scenario. However, combining the two processes (Fig.3) facilitates a better understanding of load and energy transfer between the point of impact and the occupant. For example, investigation of the crash site and aircraft wreckage provides physical data on the geometry and properties of ground and contact area, distance of the contact, failure locations, seat behaviour, occupant injuries, etc. Modelling in contrast, provides physical estimates of the level of the load generated within the aircraft/occupant. In addition, modelling can be used to aid the validation of various judgements made at the crash site concerning the sequence of events, speed and orientation at impact and so on.

Impact modelling can be achieved through a simplified lumped mass idealisation where the properties of the segments of the aircraft are represented by simple beam-like elements or through finely meshed Finite Element representation (Fig.9a). The main two difficulties with detailed modelling are the lack of access to detailed structural data and the time consuming (manpower and computer cpu) nature of the fine mesh, Finite Element technique.

It has been found that a simplified model developed using information supplied by the manufacturers, (or from data generated from past tests on complete aircraft or sub-structures) and using information collected at the accident site matched by good engineering judgement, can enable a simulation of a crash scenario to be made. Such a model can enable engineers to compute the acceleration pulse at any point of interest (Fig.3) as well as reproduce the failure mechanisms resulting from the crash and the kinematics of broken components, occupants, cargo, etc. Detailed assessment of the dynamic behaviour of any item (occupant or otherwise) within the fuselage can be made by modelling the item to the degree of complexity required and subjecting it to the crash pulse already predicted on the fuselage from the lumped mass model. In the specific case of seat/occupant assessment, provided an acceptable pulse has been predicted which represents the acceleration at the seat position, the seat and occupant can be modelled and their dynamic behaviour throughout the crash can be simulated. To cover all relevant parameters, the seat/occupant model must also represent the occupants' residual space, (i.e. the free space between the occupant and the surrounding surfaces, as well as the compliance properties of any point on boundary of the residual space which the occupant may strike. Similar modelling techniques have to be applied if an object is likely to intrude into the residual space.

This type of analysis will result in an understanding of the likely causes of injury observed at the crash site in terms of the load type and resulting injury severity induced on the occupant. If the collapse load at the occupant contact point on the aircraft is within human tolerance limits and the energy content of the crash pulse is not excessive, injury to the occupant is minimised in turning the residual space into survival space. An impact energy transfer chain of the type outlined here, is represented by Fig.4 where, through design of energy absorption capabilities in each link, the energy transferred to the occupant can be minimised.

To recommend design features aimed at improving occupant protection, factors in either direction along the energy transfer chain may be considered. For example, if for any accident type, a majority-case accident can be defined, then effort can be applied to developing the characteristics of each link for maximum energy absorption. If the majority-case accident is survivable, the induced loads within the occupant segment (Fig. 3) will be below human tolerance loads. For correct assessment of such cases, it is necessary to access acceptable information concerning human tolerance loads.

The type of data shown in Fig.5a will be of limited use since it is of relevance to head injury related to a unidirectional acceleration resulting from a head contact. It is however shown that fatal brain injuries can occur when there has not been any head contact but there has been a severe head angular acceleration. Differences in brain injury mechanisms exist between cases of predominantly translational deceleration and cases of predominantly rotational deceleration. In the former, the brain is bruised by retardation from the scull. In the latter case, the high rotational deceleration of the brain results in excessive straining of blood vessels, often resulting in rupture. In addition to such injuries, high angular deceleration also causes bruises associated with the brain contacting the inner skull (Figs 5b, 5c and 5d). Further understanding of human tolerance loads will aid more effective development of crashworthy structures. In the case of the femur, for instance, it is shown that for a fit 60 year old male, 5kN applied for a duration of 0.5 ms will result in bone fracture (Fig.6). It is not proposed to use such data in its raw state because it is necessary to carry out the required work aimed at developing the functions which relate age, fitness, etc. to fracture loads, before such indices can be utilised with confidence. A data base of human tolerance loads would support the development of crashworthy structures.

PROCEDURES TO FACILITATE VALIDATED RECOMMENDATIONS ON CRASH PROTECTION.

Although the above method of combined crash analysis and simulation is of great help in understanding crash scenarios and enables investigators to relate cause and effect, in terms of occupant injuries, it is not applied to its full potential if crash site investigation and associated modelling techniques are not stored in a data base. Such accumulated information enhances the capability of the method as the data base increases. A proposed procedure to ensure the accumulation of data appropriate, whilst applying the method to crash analysis, is diagramatically shown in Fig.7. The procedure consists principally of two inter-related activities. The first activity involves developing a crash scenario based on crash site evidence incorporating those concerning terrain, aircraft structure, and occupants condition. The second is developing a crash scenario applying mathematical modelling which include terrain, aircraft structure, and occupant representation. This procedure requires the modelling to be simple and effective so that in conjunction with information from the crash site, numerous parametric studies can be carried out. Through an iterative approach, the model is used to correct forensic judgements made at the crash site whilst the crash site data is itself used to correct the behaviour of the model. The eventual correlation of the forensic and model-predicted crash scenarios generates a high level of confidence in the accuracy of the reconstructed crash sequence. The application of such a process has two major by-products. The first is that at the conclusion of the accident investigation the model has been extensively correlated with crash site data hence, it can be used to carry out any number of what-if scenarios aimed at developing new safety recommendations. The second concern the accumulation of the data base of aircraft types, aircraft related data collated at previous crash sites, and occupant related data recorded from the past air crashes. Such data bases enhance investigators ability to reconstruct accidents faster and more accurately. It is important to point out that the simplicity of the mathematical modelling suggested within this process does not limit the investigation to only simple structural representation. Detailed assessment of any sub-structure of the aircraft will require a fine mesh model, which can be carried out in isolation. This is done by using the simplified model applied to the overall crash simulation to compute load/time histories at the boundary of the sub-structure. This information defines the loading conditions for the fine mesh Finite Element analysis of the sub-structure.

For instance, the load carrying capability of a segment of the fuselage (Fig.8a and 8b) can be represented by a non-linear curve which has been either based on previously defined data, or based on sub-structural

(testing where the property and failure mechanism are monitored, Figs.8c and 8d), or finite element modelling (Fig.9a, 9b,and 9c). Whilst the sub-structural testing provides the sub-structure's overall properties, the detailed Finite Element model provides the mean by which every element of the sub-structure can be assessed.

AIR ACCIDENT INVESTIGATION TOOL (AAIT).

The concept diagramatically shown in Fig.7 has been partially developed and applied to the investigation of several air accidents. In its present state it can be used in line with the principles defined by Fig.7, to investigate a number of crash types. It has not yet been used in a "what-if" scenario mode to assess likely air crashes with the aim of recommending new safety standards which are not based on the findings from a current investigation of an air crash.

AAIT consist of several modules amongst which are:

Visualiser:	This module uses Flight Data Recorder information to reproduce the aircraft kinematics prior to aircraft contact with the ground
Pre and Post Processor:	The formatting of the input data and the manipulation of the output from AAIT is conducted through the use of this module
Structural Analysis Module:	This module facilitates the simulation of the aircraft's structural behaviour during its crash sequence.
Occupant Simulation Module:	The dynamic behaviour of occupant and aircraft seat is computed by this module.
Data bases:	AAIT has, at present one data base covering a limited number of aircraft types. This enables rapid model development of the required aircraft which in under crash investigation. Other data bases covering past accidents and occupant injuries are to be developed.

A simple model of a passenger aircraft is shown in Fig. 10. Each section of the fuselage or wing is given a property function which defines its total load carrying capability. The behaviour of its contact area with the ground is defined by non-linear external springs. The masses of aircraft, passengers, cargo and fuel are approximated throughout the model as lumped masses. In contrast more detailed modelling is represented by that developed for a light aircraft (Fig. 11a). Figs. 11b and 11c represent a simple application of the "virtual reality" visualiser to this model. A more realistic visual representation of the aircraft, if required, can be made by adding solid shading to the image. However, in most circumstances, simple representation (Fig. 11d) will allow rapid and adequate reproduction of the crash scenario.

This type of crash simulation predicts crash pulses at any point of interest within the model. If interest relates to the seat/occupant behaviour, the occupant simulation module is activated. Use of this module will predict the seat structure behaviour, occupant kinematics and the forces/acceleration induced within the occupant segments (Figs. 12a and 12b).

AAIT has already been used to investigate a number of air crashes and has contributed towards specifying various crash safety related recommendations.

It is important to point out that software such as AAIT can also be used without reference to air crashes to study the effectiveness of existing safety standards. Typical of such activity is the use of an occupant simulation module where, in conjunction with sled tests, various means of child restraint were studied (Figs. 13a and 13b). This work resulted in new recommendations concerning child restraints.

CONCLUDING REMARKS.

The limited experience of the use of the hybrid approach to air accident investigation has proved the benefit of such procedures in terms of a better understanding of a crash event. It allows investigators to associate aircraft kinematics with forces failure mechanisms and time histories. Relating such data to occupant behaviour, the causes of injury can be established through parametric studies and hence means of reducing/eliminating the cause can be identified. The effectiveness of the hybrid approach described in this paper will be greatly enhanced as the data bases used in the process develop in size.

ACKNOWLEDGEMENTS.

The information referred to in this paper is based on research activities carried out at CICL. AAIT in the main, is developed by Dr. A. C. Walton and Dr. S. Whayeb, funded by the Ministry of Defence (UK) and the Air Accident Investigation Branch (UK). The structural analysis and occupant simulation modules incorporated into AAIT are based on computer codes developed under the FAA funding by M.G. Wittlin (Dymanic Reseponse Inc.) and Prof. D. Laananen (Arizona State University) respectively.

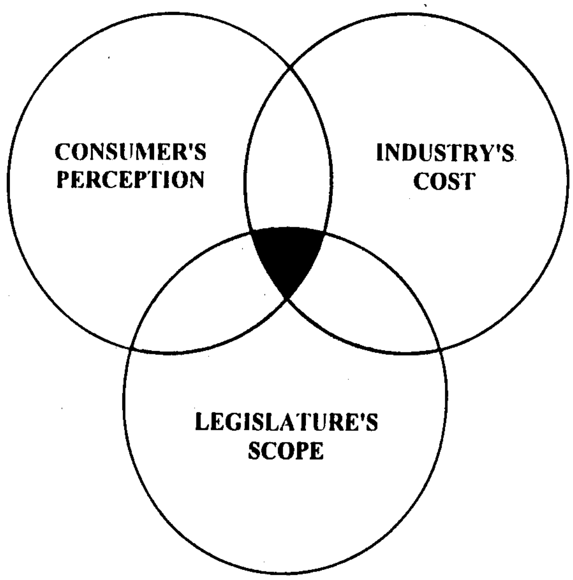


Fig. 1.

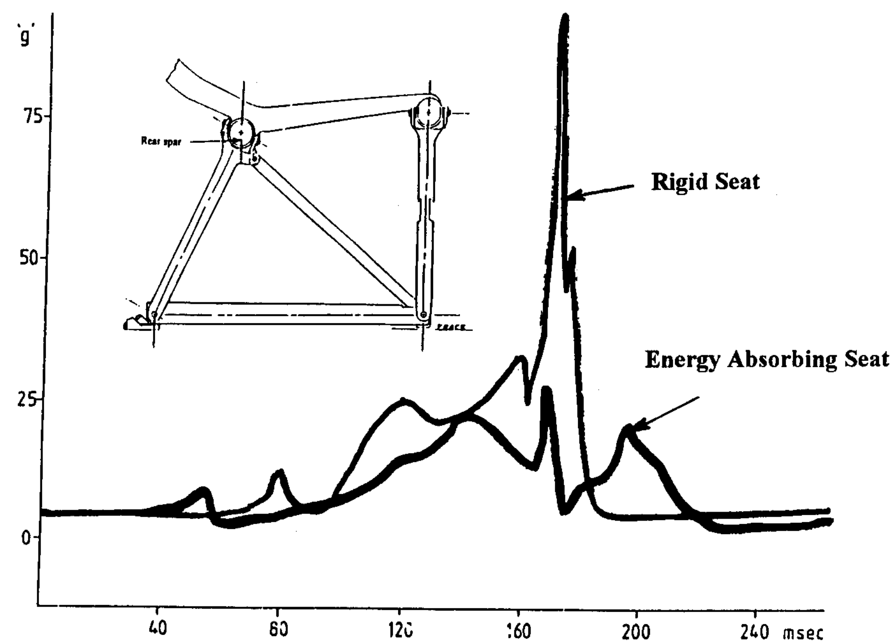


Fig. 2. Head Acceleration

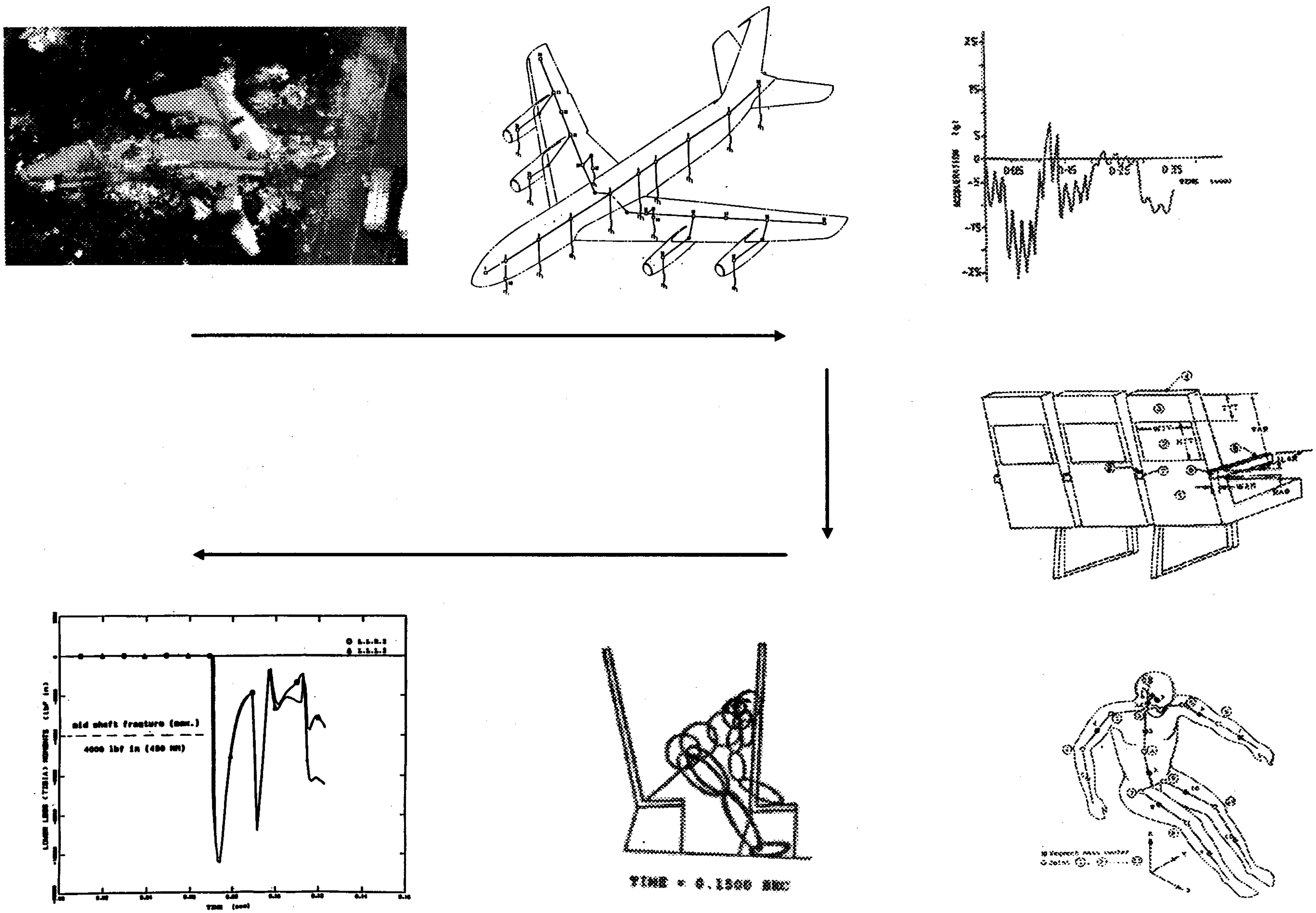


Fig 3

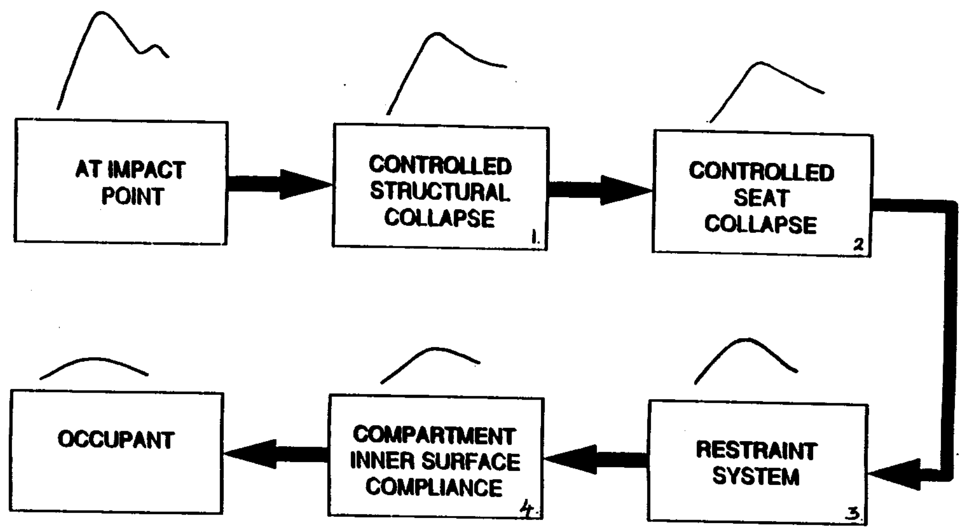


Fig. 4. Velocity Change

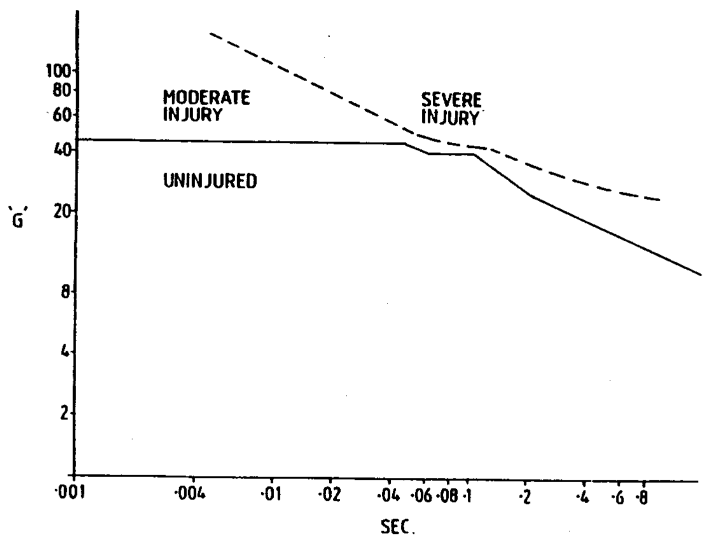


Fig. 5a.

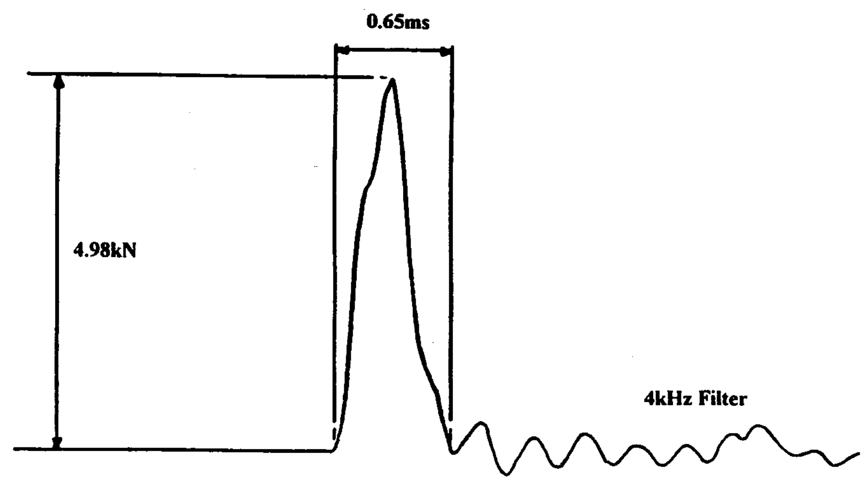


Fig. 6.

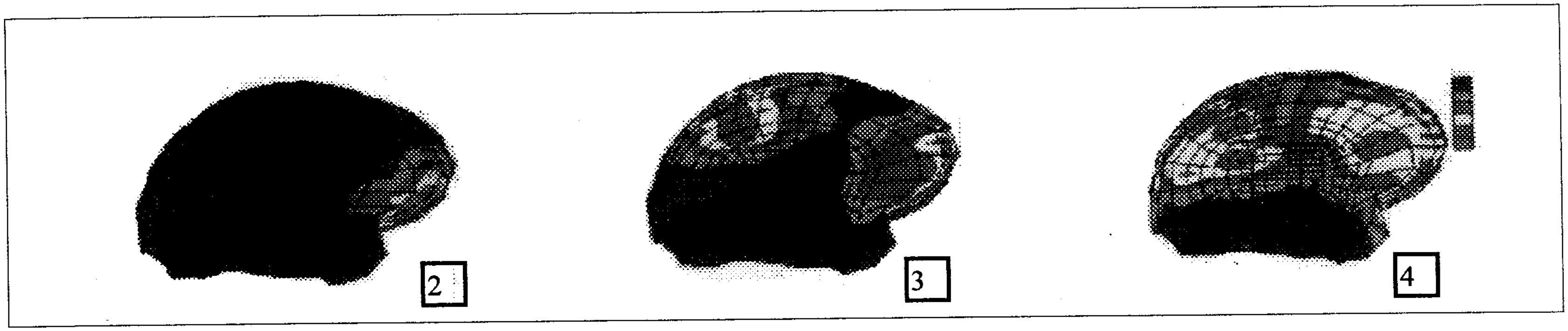


Fig 5b - Pitching motion

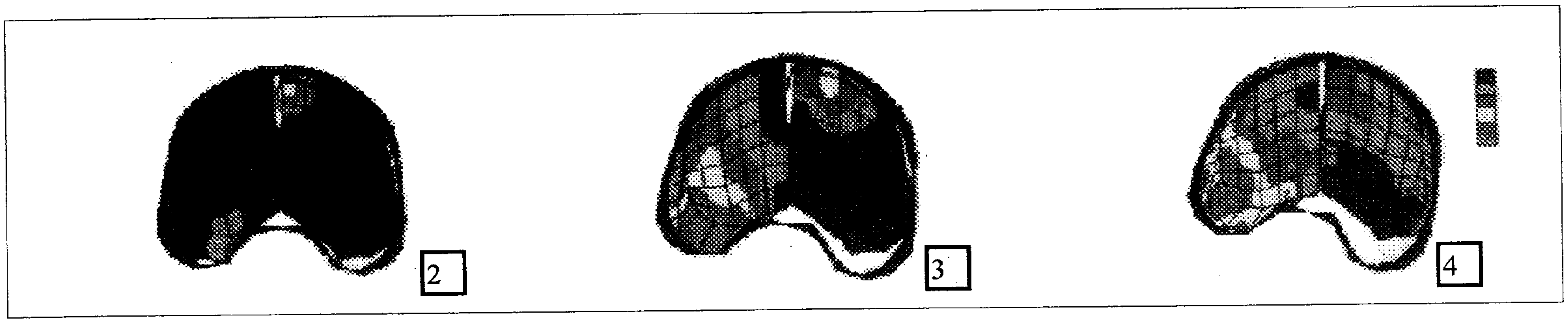


Fig 5c - Roll motion

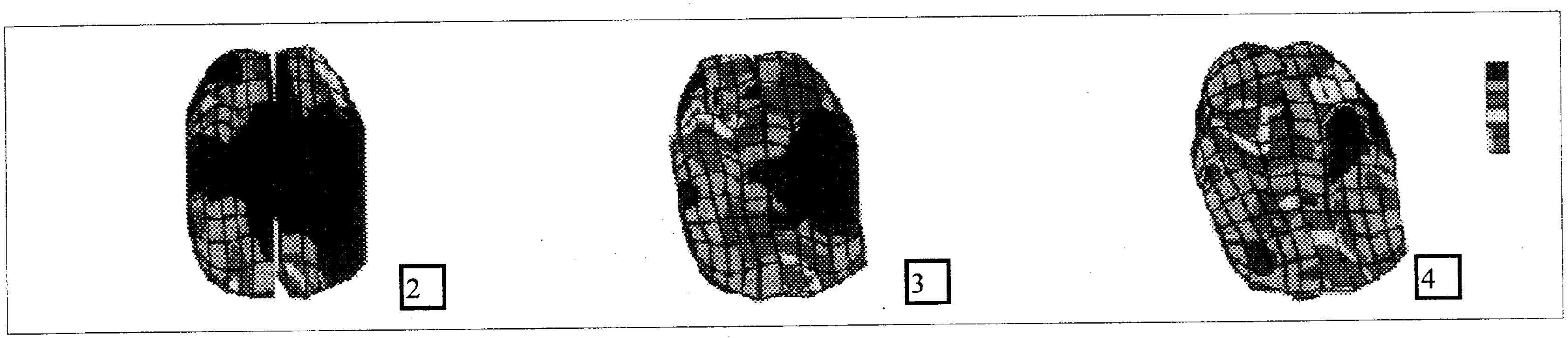


Fig 5d - Yaw motion

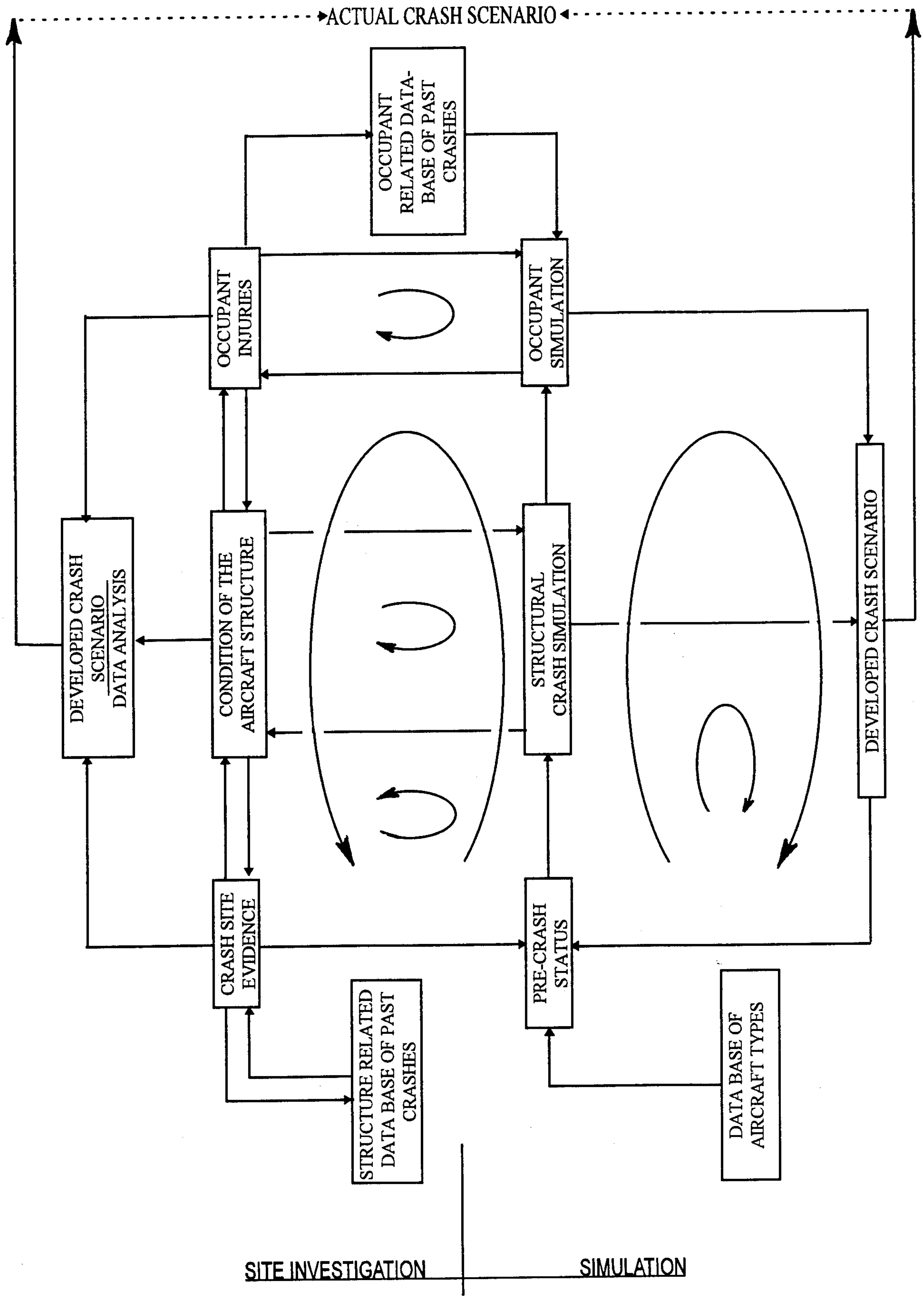

ACTUAL CRASH SCENARIO
OCCUPANT RELATED DATA-BASE OF PAST CRASHES
DEVELOPED CRASH SCENARIO
DATA ANALYSIS
OCCUPANT INJURIES
OCCUPANT SIMULATION
CONDITION OF THE AIRCRAFT STRUCTURE
STRUCTURAL CRASH SIMULATION
DEVELOPED CRASH SCENARIO
CRASH SITE EVIDENCE
PRE-CRASH STATUS
STRUCTURE RELATED DATA BASE OF PAST CRASHES
DATA BASE OF AIRCRAFT TYPES
SITE INVESTIGATION
SIMULATION

Fig 7

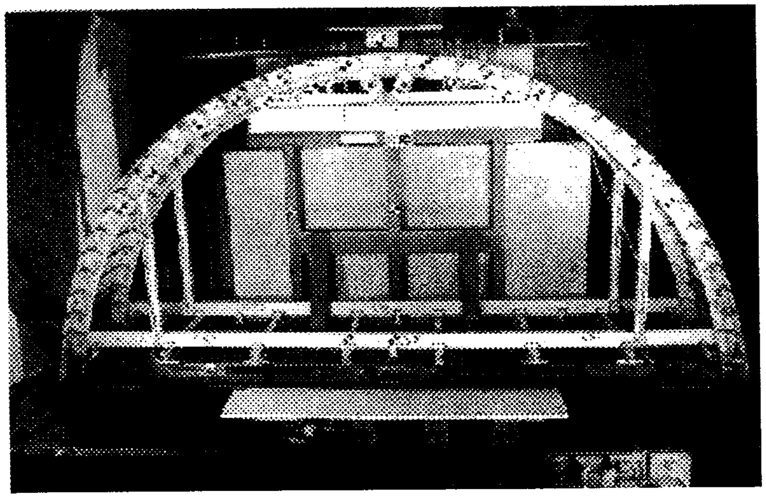


Fig 8a

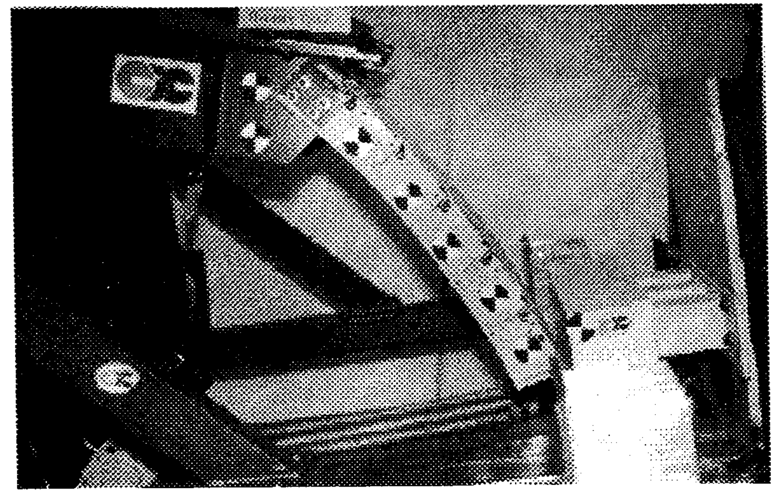


Fig 8b

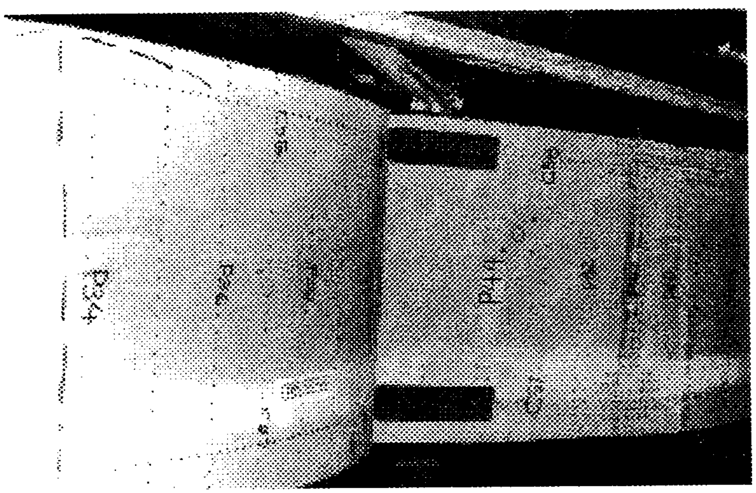


Fig 8c

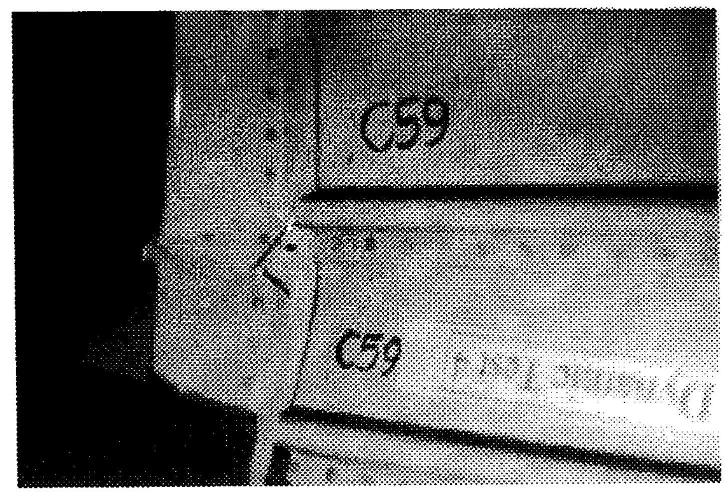


Fig 8d

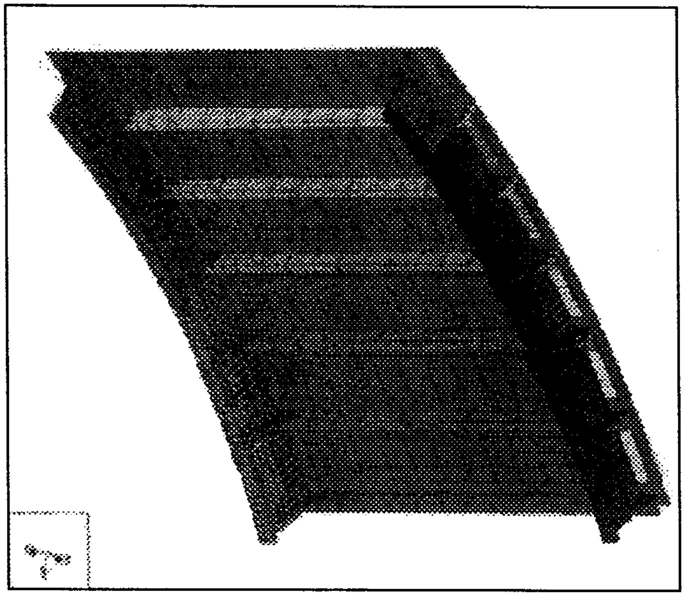


Fig 9a

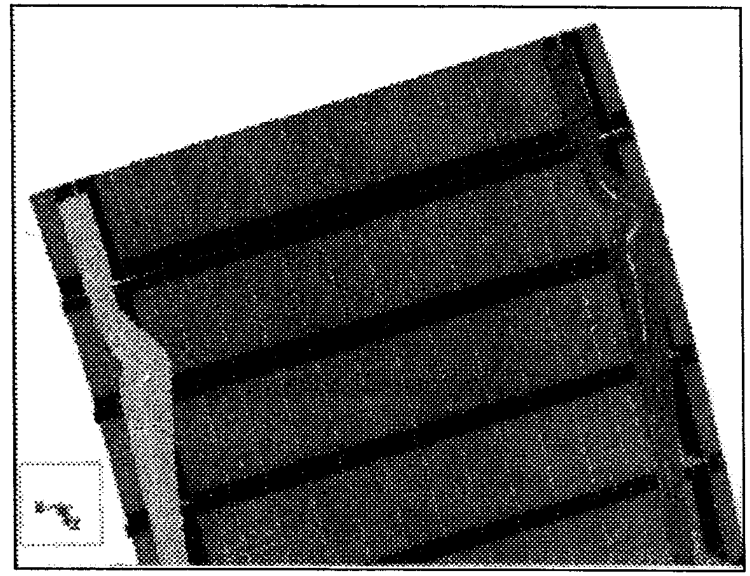


Fig 9b

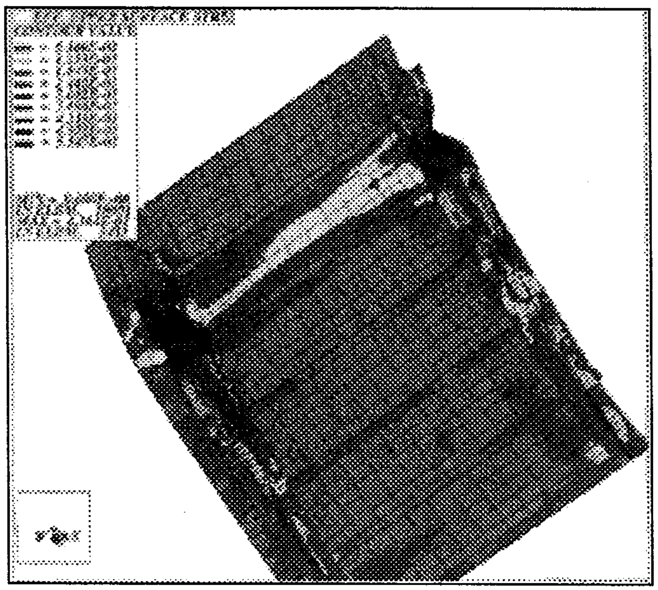


Fig 9c

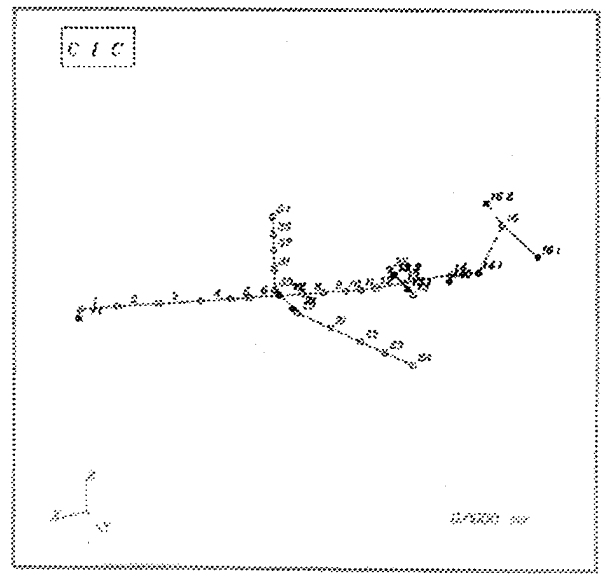


Fig 10

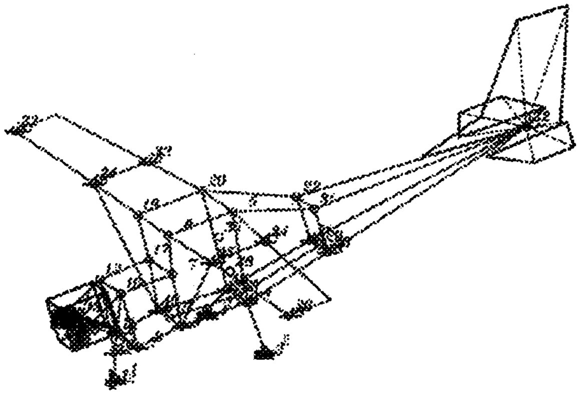


Fig 11a

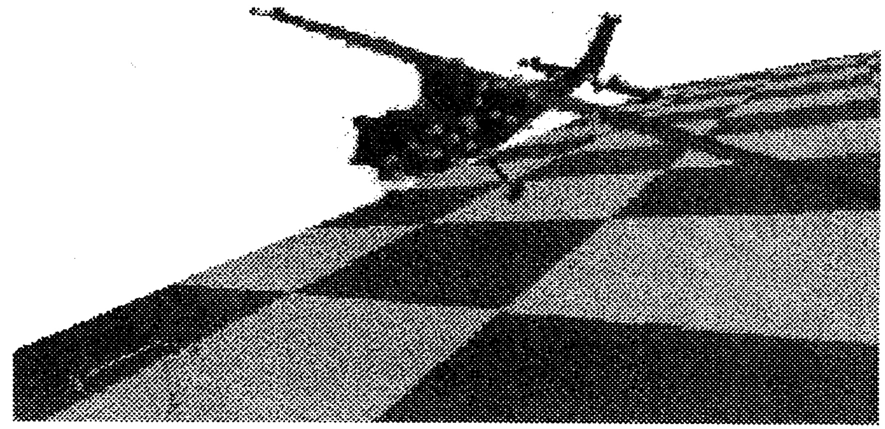
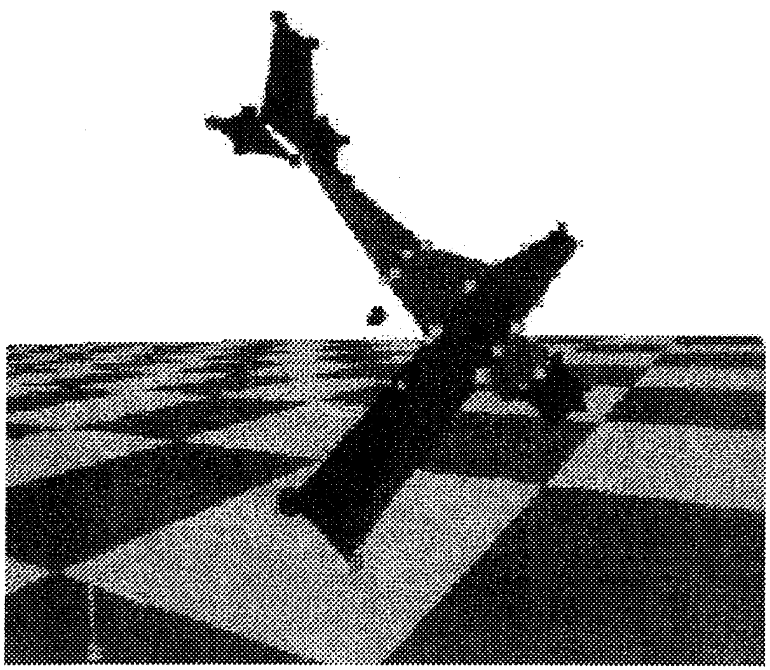


Fig 11b



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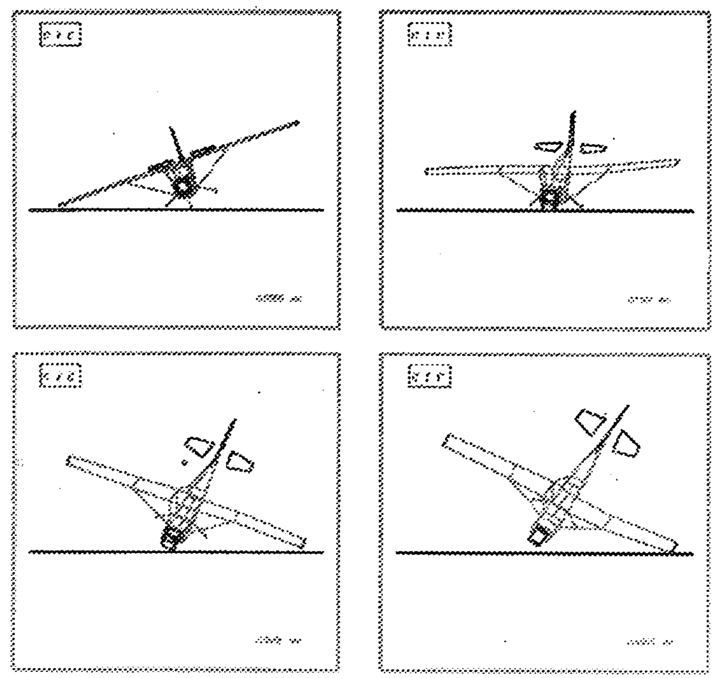

Fig 11d

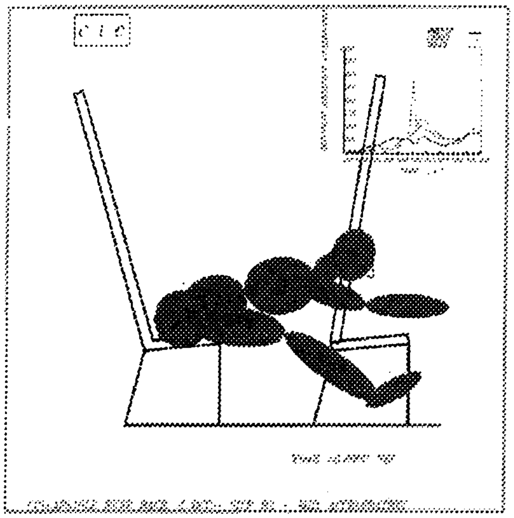

Fig 12a

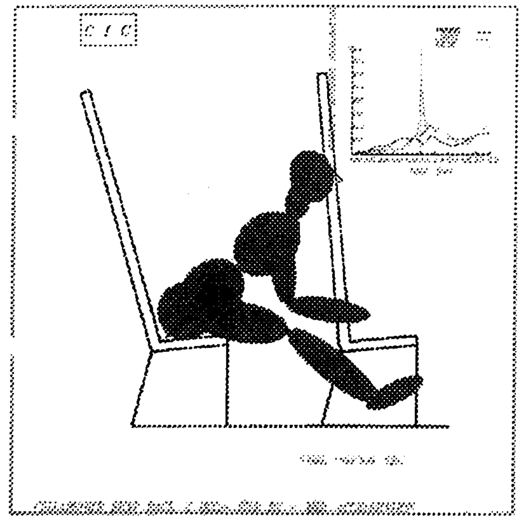

Fig 12b

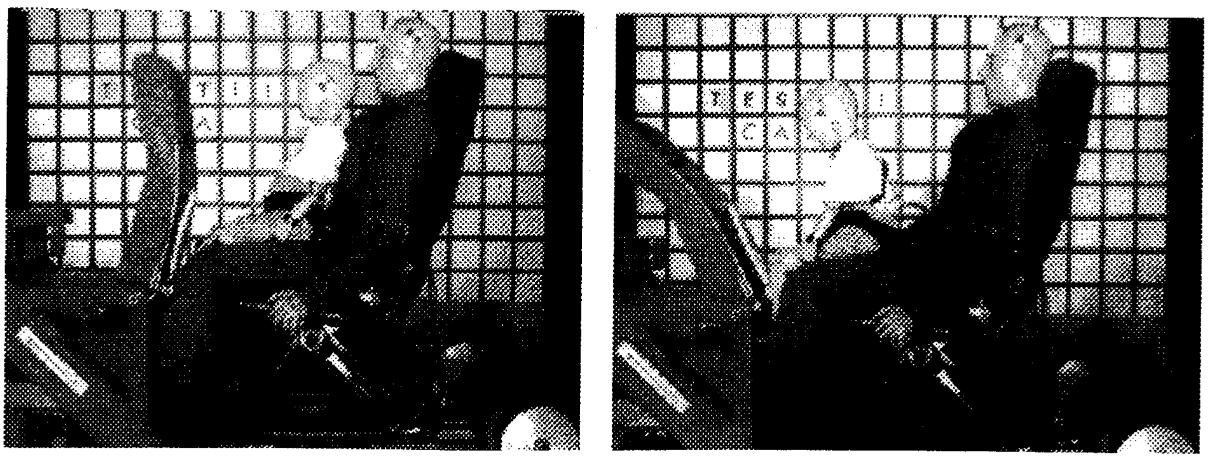

Fig 13a

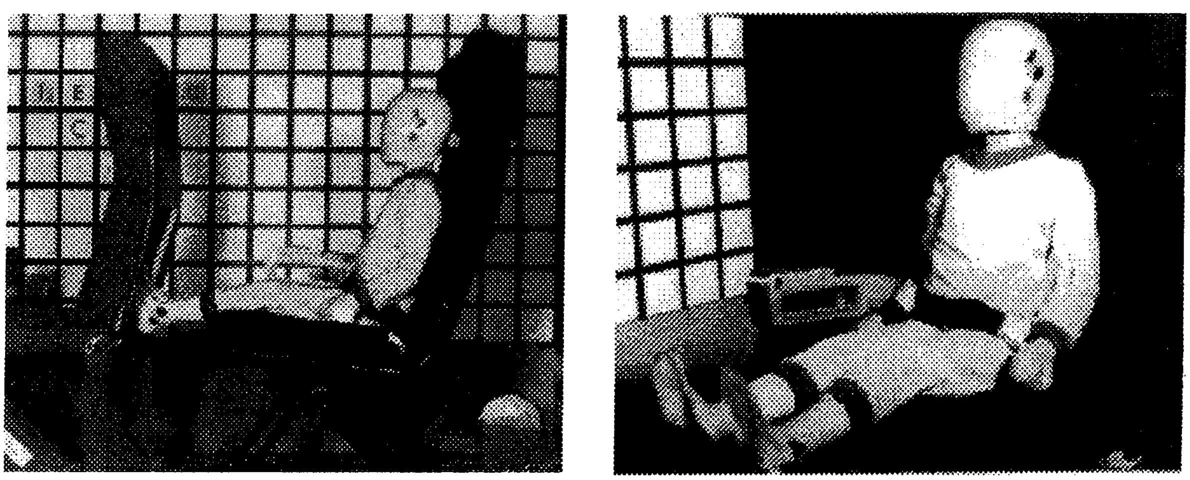

Fig 13b

AIR BAG SYSTEMS IN AIRCRAFT

Thomas H. Barth

Simula Government Products Inc.
Phoenix, AZ

ABSTRACT

Development of air bag technology for aircraft has greatly increased in the last few years, and the day when systems will be used in flight quickly approaches. This paper provides a background from which to contemplate the future of aircraft cabin safety with respect to air bag technology. The background provides a historical perspective of air bags and how they relate to aircraft. The current status of air bag technology relating to aircraft is then summarized. Included are overviews of military helicopter cockpit and commercial transport aircraft air bag development programs. Recommendations and comments on future requirements and potential improvements to air bag technology are also given.

INTRODUCTION

Due to their widespread use in automobiles, inflatable restraints or "air bags" have become a household word. The general public is routinely exposed to slow-motion automobile impact test footage in television commercials as the marketability of safety soars. Air bags have been a major contributor to the public's increased concern for safety, partly because of the astonishing stories of saved lives in would-be fatal crashes. The protective capabilities of air bags are clear and high reliability has been demonstrated by the millions of air-bag-equipped automobiles on the road. This trend has certainly contributed to a renewed interest in air bag technology for aircraft. Development programs are in place with production and installation into aircraft planned for later 1996 and 1997. Although much of the technology is similar to automotive systems, the design of air bags for aircraft have different requirements. What is the future of inflatable restraint technology for aircraft? This paper will provide some context to ponder that question.

HISTORICAL PERSPECTIVE OF AIR BAGS

The patent awarded to John W. Hetrick in 1953 marked the beginning of the air bag concept for occupant protection. By the early 1960's, automotive and aviation evaluations of the technology were in progress. These evaluations, conducted by the Federal Aviation Administration (FAA), the National Highway Transportation Safety Association (NHTSA), Ford, General Motors, and others, identified the basic technical challenges facing air bag technology. If air bags were to be successful, the bag had to be inflated before the occupant struck the interior of the vehicle. Using the vehicle impact to trigger activation, after screening out minor impacts in which the bag must not deploy, there are about fifty milliseconds in which to inflate the bag. With this constraint, two features

had to be developed: 1) a quick, accurate sensing capability, and 2) methods of quick, safe bag inflation.

Early air bag research demonstrated the feasibility of using air bags to provide protection by successfully avoiding the sensor and inflator issues. Tests using pre-inflated air bag systems demonstrated the ability to decelerate the occupant safely during a crash. The need for energy absorption to prevent excessive occupant rebound was also demonstrated. For example, the Martin Company experimented with pre-inflated air bag systems in a variety of aircraft crash tests, including an FAA crash test of a Douglas DC-7 in April of 1964. An excellent source for the early history of air bag technology as well as a comprehensive list of source documentation is the Advisory Group for Aerospace Research and Development (AGARD) report titled "Advanced Techniques in Crash Impact Protection and Emergency Egress from Air Transport Aircraft" (R. G. Snyder, 1976). Through the 1960's, Government and industry research programs (primarily automotive) were instrumental in developing and identifying needed technology. In 1969, the Secretary of Transportation issued an advance notice of proposed rulemaking regarding the use of air bags for automobiles. Air bag development activities for automotive applications greatly increased following this announcement.

Air bags became popular for automobiles once the technology proved successful, and once the safety benefits were recognized. The technology came of age in the 1970's, but air bags did not become widely used until the mid-1980's. Crash sensor technology developed by Allen Breed, and inflator technology developed by Morton International were instrumental to the cause. Field tests were conducted by Ford in 1972 by installing air bags in 831 Mercury automobiles which were delivered to insurance companies and individuals in the industry. General Motors launched a test fleet of 1,000 Chevrolet Impalas in 1973. In 1974-1976, General Motors made air bags available as an option, selling just over 10,000 vehicles with air bag systems. An excellent reliability record had been established for air bags by this time. However, it was about ten years later that the combination of regulations and newfound safety marketability enabled air bags to become common in automobiles. In 1984, Mercedes Benz offered air bags as an option, making them standard equipment two years later. Other manufacturers followed suit. Currently in 1995, over fifty million air bags are in service, and regulations are in place to phase them in for all cars and light trucks by 1998.

Limited research and development of air bag technology for aircraft occurred during the mid-1970's through the 1980's. Most notably, the U.S. Navy conducted air bag research for aircraft ejection seats and helicopter crewstations in the early 1980's. Just as in the automotive industry, standards and regulations have played a critical role in the development of aircraft safety technology. These standards and regulations, as discussed in the next section, provide the impact conditions and the means of assessing occupant protection for the development of safety systems.

AIRCRAFT STANDARDS AND REGULATIONS FOR OCCUPANT PROTECTION

In 1969, the U.S. Army issued the Crash Survival Design Guide (Turnbow, et al, 1969). This report, based on work done by Dynamic Science and the Flight Safety Foundation, provided a guide for aircraft crashworthy design. The report also established the impact conditions for aircraft. The impact conditions were divided into one set for helicopters and light fixed-wing aircraft and another set for transport aircraft. The impact conditions were based on actual crash data for survivable accidents involving substantial structural damage or occupant injury. Vertical and longitudinal impact conditions were given in the form of an idealized acceleration time-history in the form of a triangular crash pulse. The magnitude of the triangular crash pulse was set at a level corresponding to 95 percent of the survivable accident database. The Crash Survival Design Guide also summarized human tolerance limits in the vertical, forward, and aft directions for a seated occupant. Human tolerance limits were expressed in terms of exposure to acceleration, qualified by stating the configuration used. For example, the vertical down limit is expressed as "approximately 15 G for a duration of 0.1 second", followed by a statement that it is based on test data using a shoulder harness/seat belt restraint with a seat belt tie-down strap.

A major revision of the Crash Survival Design Guide done in 1980 eliminated discussions of fixed-wing aircraft. The current document addresses only helicopters. Dynamic impact conditions for fixed-wing aircraft did not become established standards until the 1988 revisions to the United States and European airworthiness regulations. Amendments to Federal Aviation Regulation and Joint Airworthiness Regulations in 1988 introduced requirements for improved occupant protection during a survivable crash. Dynamic performance standards replaced the existing static standards. Dynamic testing now made it possible to use quantitative methods of measuring the potential for human impact injury through the use of instrumented Anthropomorphic Test Dummies (ATD's). Typically air bag systems primarily protect the head from striking the interior of the vehicle. During crash testing, head injury is assessed from data collected by the accelerometers mounted in the head of the ATD. The potential for head strike injury is expressed in terms of the Head Injury Criterion (HIC). HIC values are calculated from the resultant head acceleration of the ATD. The value of 1,000 has been established as the threshold of serious head impact injury. For repeatability and standardization of test results, the regulations require the use of a Title 49 Code of Federal Regulations, Part 572 ATD. The Hybrid II ATD developed by General Motors meets this requirement.

RECENT DEVELOPMENTS IN AIR BAGS FOR AIRCRAFT

Survivable aircraft crashes can cause serious head injury to the occupants due to their striking the interior components of the aircraft. The restraint systems and the interiors of modern aircraft have been designed to reduce these injuries. However, for many aircraft, the restraint systems do not provide

adequate protection, and operational constraints preclude adequate delethalization of the interior. Air bag systems are currently being developed to provide head strike protection for both rotary-wing and fixed-wing aircraft.

The following sections provide a brief background and description of the three air bag systems currently in development for aircraft. These systems have similar primary components that share the same function, but differ in design. The systems consist of a crash sensor/diagnostics (CSD) module, gas generator(s), and the air bag(s). The CSD module contains diagnostic electronics, a firing circuit, and sensor(s). During the aircraft crash impact, the CSD module senses the crash and delivers an electrical pulse to the gas generator. This impulse ignites propellant within the gas generator, which produces the gas to inflate the air bag to protect the occupant.

INFLATABLE BODY AND HEAD RESTRAINT SYSTEM (IBAHRS)

The Inflatable Body and Head Restraint System or IBAHRS is a restraint system with inflatable bladders (air bags) mounted to the crewseat shoulder harness straps. Crash injury research has shown that occupants using the current military restraint systems with double shoulder straps are susceptible to lethal head strikes with the interior of the helicopter. The IBAHRS system improves occupant protection during a survivable crash by removing slack from the restraint system and providing support for the occupant's head. Initial development work on this system was conducted by the Naval Air Warfare Center (NAWC) at Warminster, Pennsylvania, in the 1980's. In 1991, Simula Government Products, Inc., was awarded a contract to complete the development of the system. The IBAHRS system completed qualification testing in 1995, with planned introduction into U.S. Navy AH-1W Super Cobra helicopters in 1996. As a restraint-mounted system, the IBAHRS has the advantage of not requiring mounting space on the crowded instrument panel.

The system has a gas generator and air bag mounted on each shoulder strap. In the stowed condition, the bag is folded around the gas generator and strap, and is contained in a fabric enclosure. The enclosure contains frangible seams that open upon bag inflation. The IBAHRS system is shown in the deployed condition in Figure 1.

Figure 1: Inflatable Body and Head Restraint System

COCKPIT AIR BAG SYSTEM (CABS)

The development of the Cockpit Air Bag System or CABS was based on transferring automotive technology to attack helicopter crewstations. Initial U.S. Army-sponsored feasibility studies have been completed, and now a program is in progress to develop the system for the AH-64 Apache helicopter. The system has a planned introduction date of 1997.

The CABS contains three air bags, one on each side of the occupant and one in front of the occupant. Each bag is inflated by an individual gas generator. The bags are non-vented to remain inflated for the entire crash. These bags minimize occupant flailing and provide protection in lateral impacts, such as an aircraft rollover. The CABS system is shown in Figure 2.

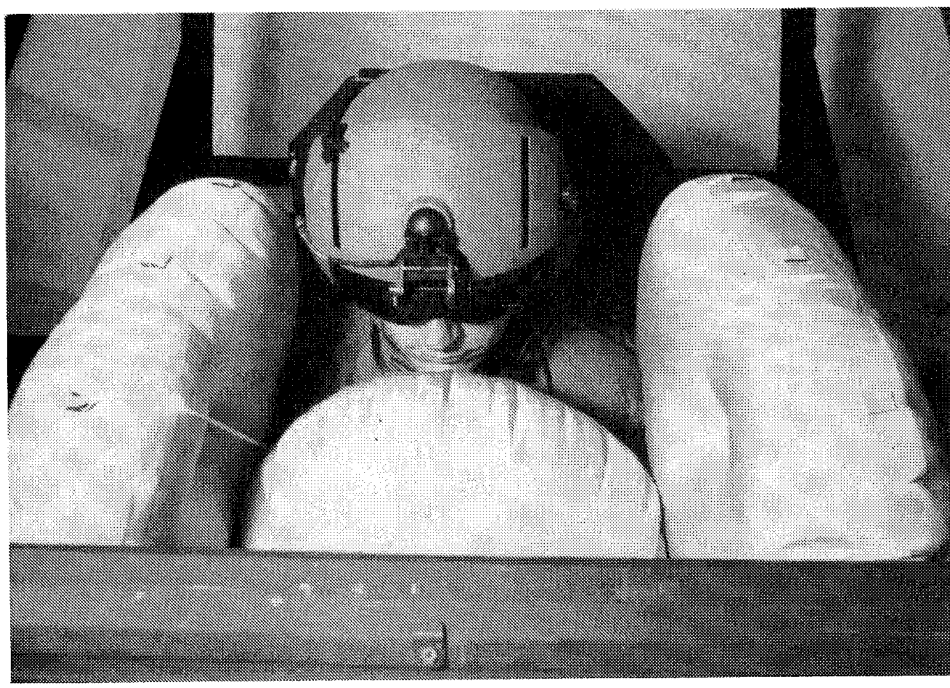

Figure 2: Cockpit Air Bag System

Figure 3 is a photo of the Active Crew Restraint Demonstration Testing conducted at the NASA Langley Research Center (Hampton, Virginia) in 1993. Two full-scale crash tests were conducted to demonstrate the performance of the IBAHRS and CABS systems. The tests indicated that both restraint systems performed as designed.

Figure 3: Aircraft Crash Test of IBAHRS and CABS

BULKHEAD AIR BAG SYSTEM (BABS)

A development program is currently underway for application of the bulkhead air bag system or BABS into the Jetstream Aircraft Ltd. 4100 transport aircraft. The bulkhead air bag system was developed by Simula to provide a means of passive supplemental restraint for front-row seated passengers on transport aircraft. The head strike protection requirement (FAR/JAR 25.562) has been particularly difficult to meet for the front-row seat positions located behind interior cabin structures. Certification authorities have granted temporary exemptions from the head strike requirement for aircraft covered by the regulation as methods of compliance are developed. Cooperative efforts to establish a certification basis for the system are in process between Jetstream, Simula, and the regulatory agencies. Introduction of the system is expected in 1997.

During the crash event, sensors within the Bulkhead Air Bag System detect the crash pulse and initiate system deployment. Passenger head strike protection is provided by a rapidly inflating air bag that deploys from a module mounted on the cabin structure in front of the occupant. The air bag acts as a cushion between the passenger and the strike hazard. Occupant interaction with the bag attenuates occupant energy and provides head injury protection. The air bag system is armed from the control panel, which also contains indicators to report system readiness and faults. The photos shown in Figure 5 were taken during dynamic sled tests performed at the FAA's Civil Aeromedical Institute (CAMI) during demonstration testing in December of 1993. The first photo shows the sled just prior to the deployment. In the second photo, the occupant is shown loading into the deployed air bag as the sled decelerates.

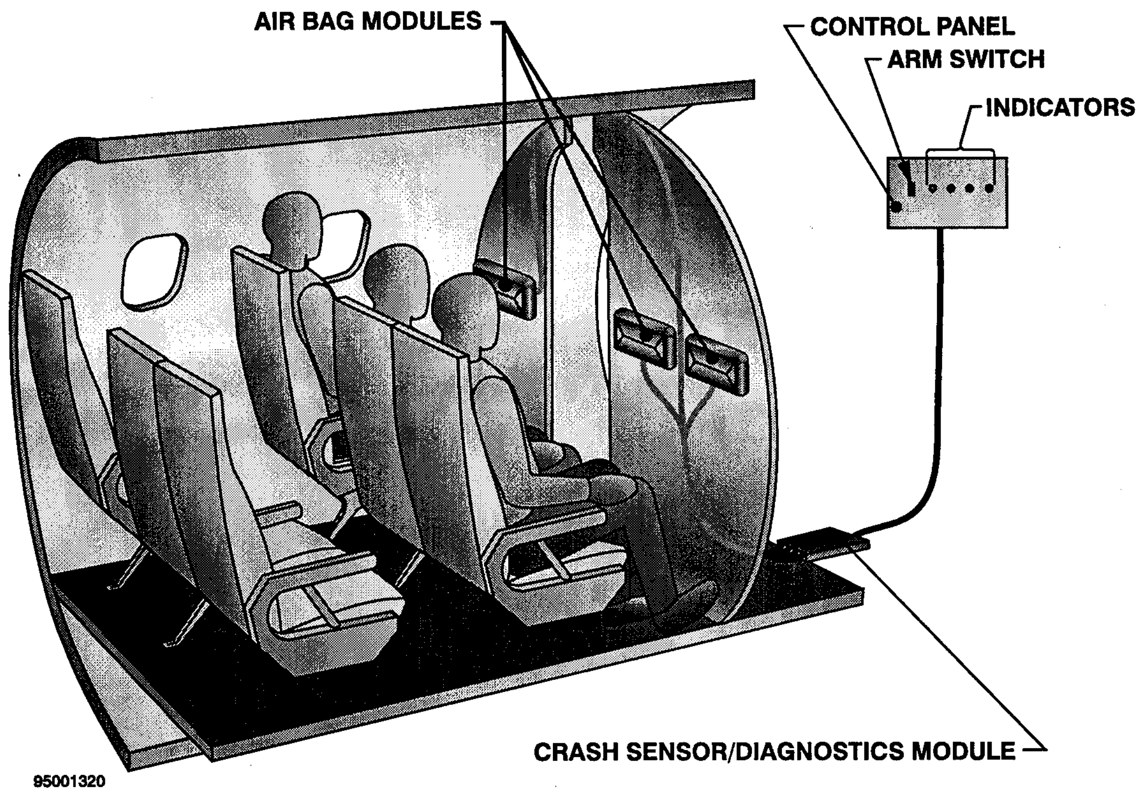

Figure 5: Deployment Sequence

During the crash event, sensors within the Bulkhead Air Bag System detect the crash pulse and initiate system deployment. Passenger head strike protection is provided by a rapidly inflating air bag that deploys from a module mounted on the cabin structure in front of the occupant. The air bag acts as a cushion between the passenger and the strike hazard. Occupant interaction with the bag attenuates occupant energy and provides head injury protection. The air bag system is armed from the control panel, which also contains indicators to report system readiness and faults. The photos shown in Figure 5 were taken during dynamic sled tests performed at the FAA's Civil Aeromedical Institute (CAMI) during demonstration testing in December of 1993. The first photo shows the sled just prior to the deployment. In the second photo, the occupant is shown loading into the deployed air bag as the sled decelerates.

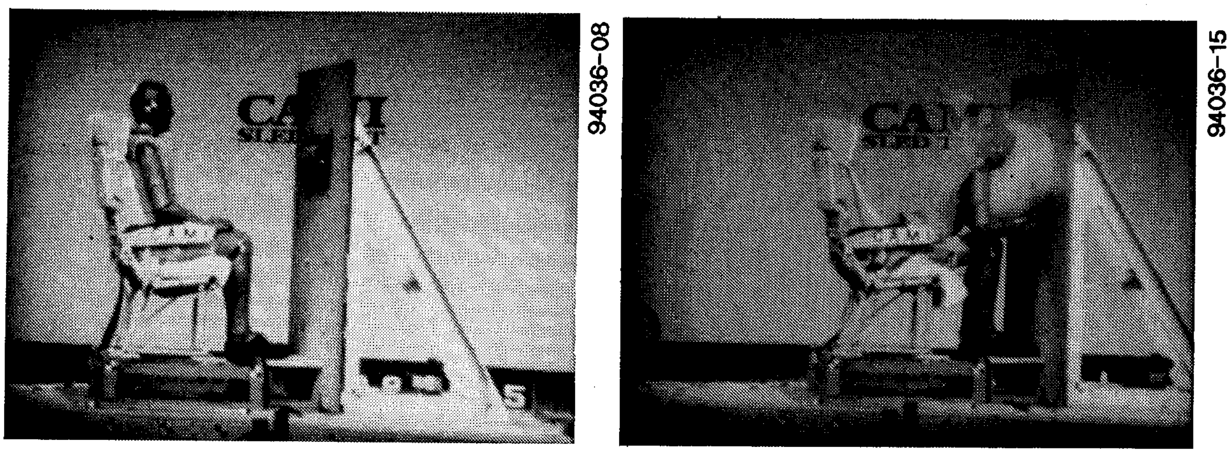

Figure 5: Deployment Sequence

FUTURE NEEDS FOR AIRCRAFT AIR BAG RESEARCH

The future development of aircraft inflatable restraints will need to address the specific needs of aircraft design and requirements. The following paragraphs provide some insight and comments regarding technical improvements and other needs to help the progression of aircraft air bag technology.

The materials used in the construction of inflatable restraints will need to be compatible with aircraft requirements. Materials have been developed with specific properties to meet the performance needs for air bag systems. However, these materials were developed using automotive requirements and often do not meet aircraft requirements. One example is the family of polymers that have been developed for air bag covers. Air bag covers are exposed to severe dynamic loading during the air bag deployment and thus have been developed with the physical properties to withstand these forces. Unfortunately ,these polymers do not meet all of the FAR flammability requirements. Another example is air bag fabrics. The fabrics that meet aircraft requirements have a significant weight penalty compared to the best automotive fabrics because they have lower heat resistance.

Because aircraft have more complex crash dynamics than automobiles, advanced gas generators and crash sensors could improve the effectiveness of an aircraft air bag system. Aircraft typically crash with vertical as well as longitudinal velocity components, and may experience multiple severe impacts. Advanced gas generators could be developed to provide extended- or multiple-inflation capabilities. Sensors could be developed with the ability to sense out-of-position occupants, multiple impacts, and to record flight data.

Databases and analytical methods need to be improved to facilitate air bag development. The current aircraft crash databases suffer from being either too limited or too general for use in air bag design. Routine crash testing (as used in the auto industry) is cost-prohibitive for aircraft, and detailed airframe crash dynamic analysis with respect to air bag design does not exist. Analytical models have promise, but a methodology to interface the models of the airframe, seat, occupant, interior, and air bag needs to be developed. Technology needs to be developed to reduce the cost of evaluating safety products. New testing concepts referred to as “component testing” show promise for reducing the amount of dynamic testing required.

One of the most important activities needed to facilitate the future development of aircraft inflatable restraints is planning, guidance, and cooperation between regulatory agencies and industry. Standard test procedures, specifications, and requirements need to be developed. Once in place, these will provide guidance for efficient product development.

SUMMARY

Air bag technology has become very sophisticated through extensive research and development within the auto industry. These advancements, driven by regulations, have created safer cars and saved many lives. Research and products already in development have shown that air bag technology can do the same for aircraft. Excellent core technology exists, but it needs to be refined to better meet aircraft requirements. Cooperation between industry and regulatory agencies can drive efficient adaptation of the technology for safer aircraft and saved lives.

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International Conference On
Cabin Safety Research

November 14 - 16, 1995

Future R&D Needs In Impact Dynamics

Stephen J. Soltis

Federal Aviation Administration

Elements of Crashworthy System Design

Airframe Structure

Strength
Impact Attenuation

Interior Furnishings

Tiedown Strength

Aircraft Seats

Strength
Occupant Injury Criteria

Post Crash Fire

Fuel Containment
Ignition Sources

Emergency Evacuation

Availability of Exits & Paths

Future R&D Needs
Airframe Structure

Main Wing Spar Seating

High Wing Airplanes

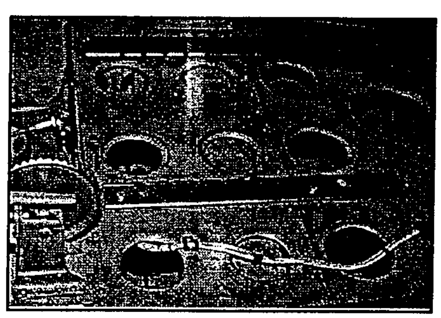
Composite Materials Structures

Unique Structures/Configurations

Future R&D Needs
Airframe Structure

Main Wing Spar Seating

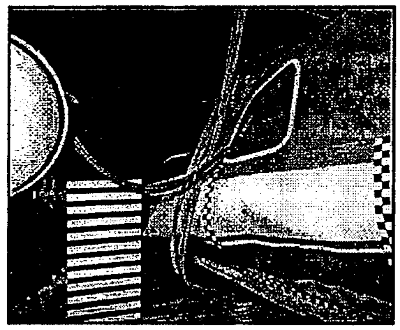
Potential Problem: Lack of Structural Deformation & Energy Absorption And Potential of Cabin Penetration



Future R&D Needs
Airframe Structure

High Wing Airplanes

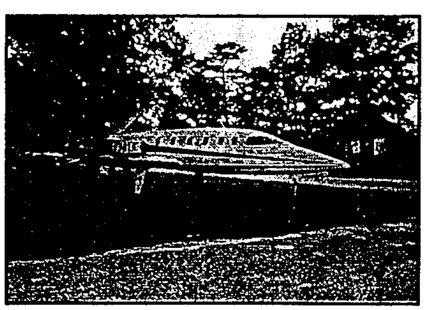
Potential Problem: Cabin Penetration and Occupant Injury

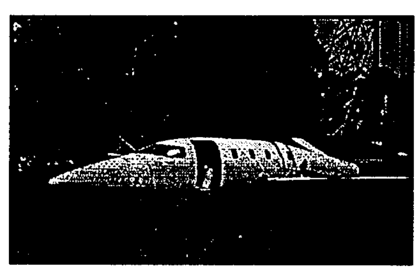


Future R&D Needs
Airframe Structure

Composite Materials Structures

Potential Problem: Lack of Structural Deformation & Energy Absorption And Hazardous Failure Modes

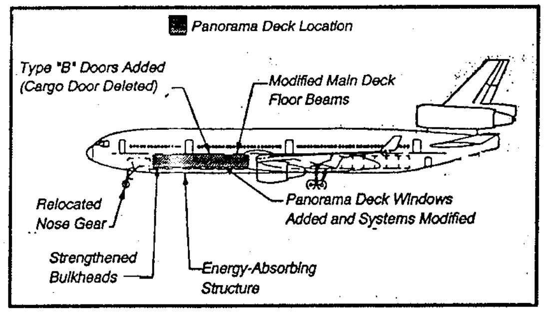




Future R&D Needs
Airframe Structure

Unique Structures / Configurations

Potential Problem: Lack of Structural Deformation & Energy Absorption And Hazardous Failure Modes



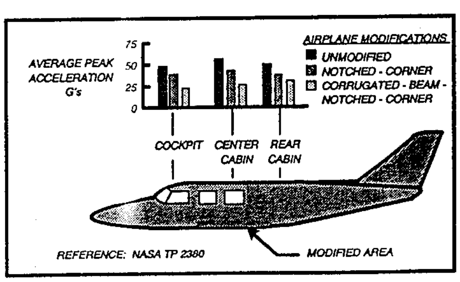
Future R&D Needs
Energy Absorbing Structures

Airplane Underfloor Structure

Head Strike Components

Pelvic/Lumbar Column Load Path

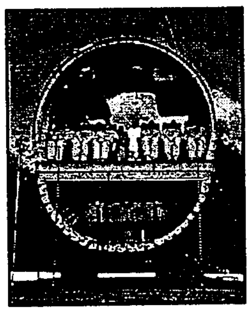
Potential Problem: Occupant Injury Due to Inadequate Energy Absorption



Future R&D Needs
Interior Furnishings

Overhead Luggage Bins

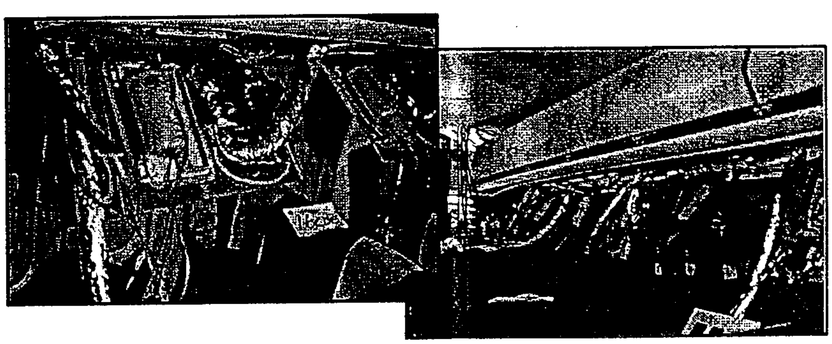
Potential Problem: Bin Separation May Cause Occupant Injury And Impediments to Emergency Evacuation



Future R&D Needs
Interior Furnishings

Passenger Service Units (PSUs)

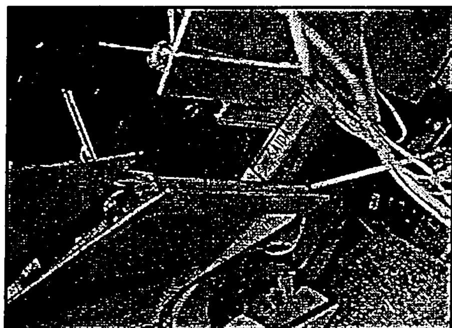
Potential Problem: PSU Separation May Cause Occupant Injury And Impediments to Emergency Evacuation



Future R&D Needs
Interior Furnishings

Other Impediments

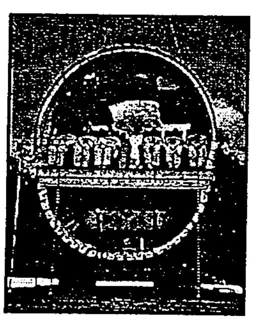
Potential Problem: Separation May Cause Occupant Injury
And Impediments to Emergency Evacuation

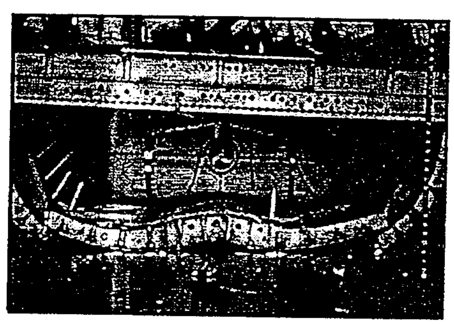


Future R&D Needs
Fuel Containment

Fuel Containment Concepts
Auxiliary Fuel Systems
Empennage Fuel Systems

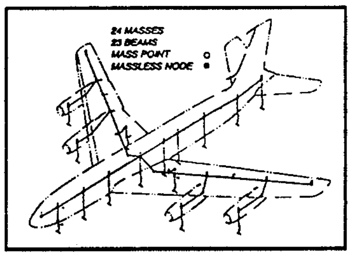
Potential Problem: Fuel Spillage and Post Crash Fire





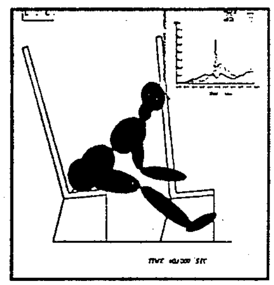
Future R&D Needs
Crash Dynamics Analytical Tools

Potential Problem: *Lack of Analytical Tools to Evaluate Aircraft Design and Occupant Impact Environment*
May Be Design Tool and Certification Aid



Typical Transport Aircraft Krash Model Used For Parameter Studies

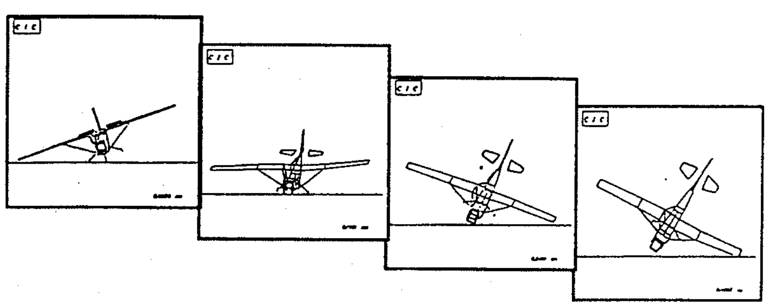
Example Seat / Occupant Model



Future R&D Needs
Air Accident Investigation Tool

Establish Partnership with CAA / Cranfield Impact Centre

Potential Problem: *Lack of Analytical Tools to Evaluate Aircraft Accident and Occupant Impact Environment*



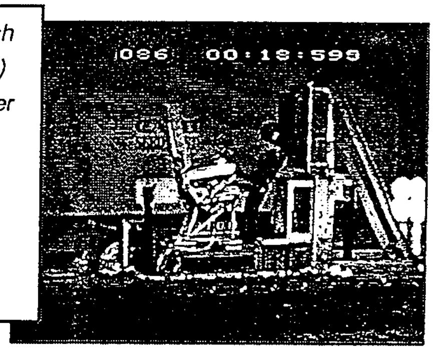
Future R&D Needs
Occupant Injury Criteria

Potential Problem: Lack of Appropriate Injury Criteria
Injury Mechanisms and Effective Means Not Fully Established For Reducing Serious Occupant Injuries

Body Regions: Head, Neck, Lower Leg, Pelvis, Pelvic/Lumbar Column

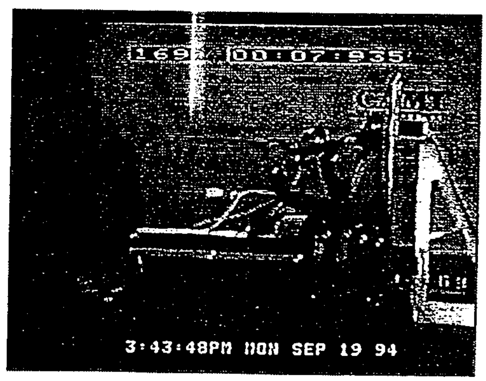
Major Survivors of M1 Aircrash
(For 87 Patients Surviving Crash)

Body Region	Number
Head Injury	43
Thoracic Injuries	23
Abdominal Injuries	2
Spinal Fractures	24
Pelvic/Lower Limb Injuries	142
Upper Limb Injuries	59



Future R&D Needs
Side Facing Aircraft Seats

Potential Problem: Lack of Appropriate Certification Standards
Occupant Restraint System Requirements and Injury Mechanisms Differ From Fwd/Aft Facing Seats



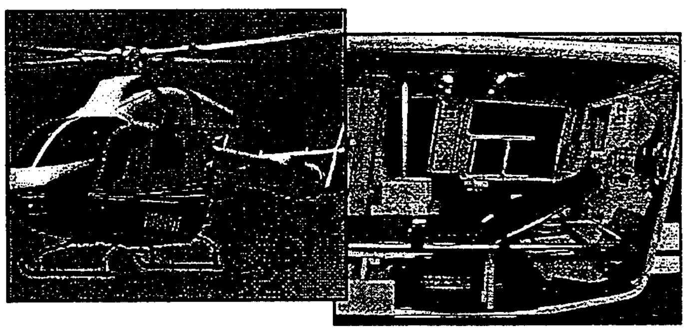
Future R&D Needs

Rotorcraft

Rotorcraft Rollover

Medivac Rotorcraft

Potential Problem: Component Separation May Cause Occupant Injury And Impediments to Emergency Evacuation



ABSTRACT

"Cabin Safety Research Plan"

Gary Frings
Federal Aviation Administration Technical Center
Aircraft Structural Crashworthiness Program
Atlantic City International Airport, New Jersey, USA

Title: Aircraft Interior Safety
Objective: Determine the response of aircraft overhead stowage bins under dynamic test conditions.
Need: Aircraft accident experience indicates that overhead stowage bins retention provisions may not be performing as designed or required. Specifically, the aircraft accidents which involved the B737 at Kegsworth and the MD88 in Stockholm indicated this.
Description: The FAA Technical Center's Crashworthiness Program has been actively involved in research involving the dynamic testing of aircraft overhead stowage bins since 1991. A ten foot long narrow body fuselage section, which had various overhead stowage bins installed, has been subjected to a series of longitudinal decellerations, and one destructive vertical drop test, to determine the reactions of the bins and attachments. The vertical drop test was intentionally structured to impose a dynamic load condition in excess of the current design and certification requirements so that the dynamic fracture loads and modes of fracture could be determined and evaluated. Technical reports have been published which document the test results.

Another narrow body fuselage section is currently being prepared, with different overhead stowage bins, for another series of tests.

Dynamic Drop Test Facility

FAA Technical Center
Atlantic City International Airport
New Jersey, USA

Gary Frings
Crashworthiness Program Manager

International Conference on
Cabin Safety Research
Atlantic City, NJ
November 14-16, 1995

Facility Capabilities

- **Current Lifting Capacity - 13,600 pounds**
- **Upgraded Lifting Capacity - 50,000 pounds**
- **Unique Platform Capability**
  - 15 feet by 36 feet
  - supported by 12 load cells
  - platform acceleration can be measured
- **Ninety-two channel data acquisition system**

Beech 1900C Commuter Airliner Test

- Type - 19 passenger airplane
- Weight - 8,475 pounds
- Vertical velocity - 27 feet/second
- Objective - Determine the structural response of the fuselage, seats to a severe but survivable ground impact
- Results - Minimal fuselage deformation, data are being analyzed, report available in approximately six months

Transport Category Test

- Type - 10 foot long narrow body fuselage section
- Weight - 8,100 pounds
- Vertical velocity - 30 feet/second
- Objective - determine the dynamic response of the onboard overhead stowage bins and auxiliary fuel tank
- Results - Fuselage crushed 1 1/2 feet, 36g deceleration level, 57 millisecond pulse duration, overhead bins and supports fractured, well designed auxiliary fuel tank installation

Metro III Test

- Type - 19 passenger commuter airplane
- Weight - 7,530 pounds
- Vertical velocity - 26.3 feet/second
- Objective - Determine the structural response of the fuselage, floor, seats
- Results - minimal fuselage deformation (one inch), 50 to 60 g deceleration levels

Future Tests

- **Shorts 330**
  - 30 passenger, high wing, commuter airplane
- **Transport Category Section**
  - Different overhead stowage bins, different auxiliary fuel tank

CIRA S.p.A.
CENTRO ITALIANO RICERCHE AEROSPAZIALI

PRORA Programme

LISA

CRASH TEST FACILITY

for Large Aerospace Structures

FAA Cabin Safety Conference - November 1995

Motivation for a Large Crash Test Facility (L.C.T.F.)

- *Assessment of aircraft and space re-entry vehicles Crashworthiness in different Crash scenarios*
- *Landing of space re-entry capsules*
- *Incoming of more stringent Crashworthiness requirements by regulation for rotary and fixed wing aircrafts*
- *Calibration and validation of simulation methodologies and models for design optimisation*
- *Improvement of reliability and trustworthiness of Crash simulation to reduce the need of expensive full scale tests.*

"History" & "Problems"

Two test schemes are classically used for full scale Crash tests:

- ***Free flying remotely controlled aircraft***
  - ***High cost of the Test Article***
  - ***Possible inaccuracy of the impact conditions***
  - ***High risk of post-Crash fire or explosion***
- ***Pendulum Facilities***
  - ***Difficulties in obtaining accurate impact angle and aircraft attitude due to the possible lack in cable tension***

Why LISA's project

Considering:

- ***the definition of "Crash Analysis" as an high priority theme into the PRORA programme***
- ***Professor Giavotto's idea for a new concept test facility with the capability to overcome the problems of the full scale Crash***
- ***the absence of a permanent Full scale Crash Test Facility in Europe***

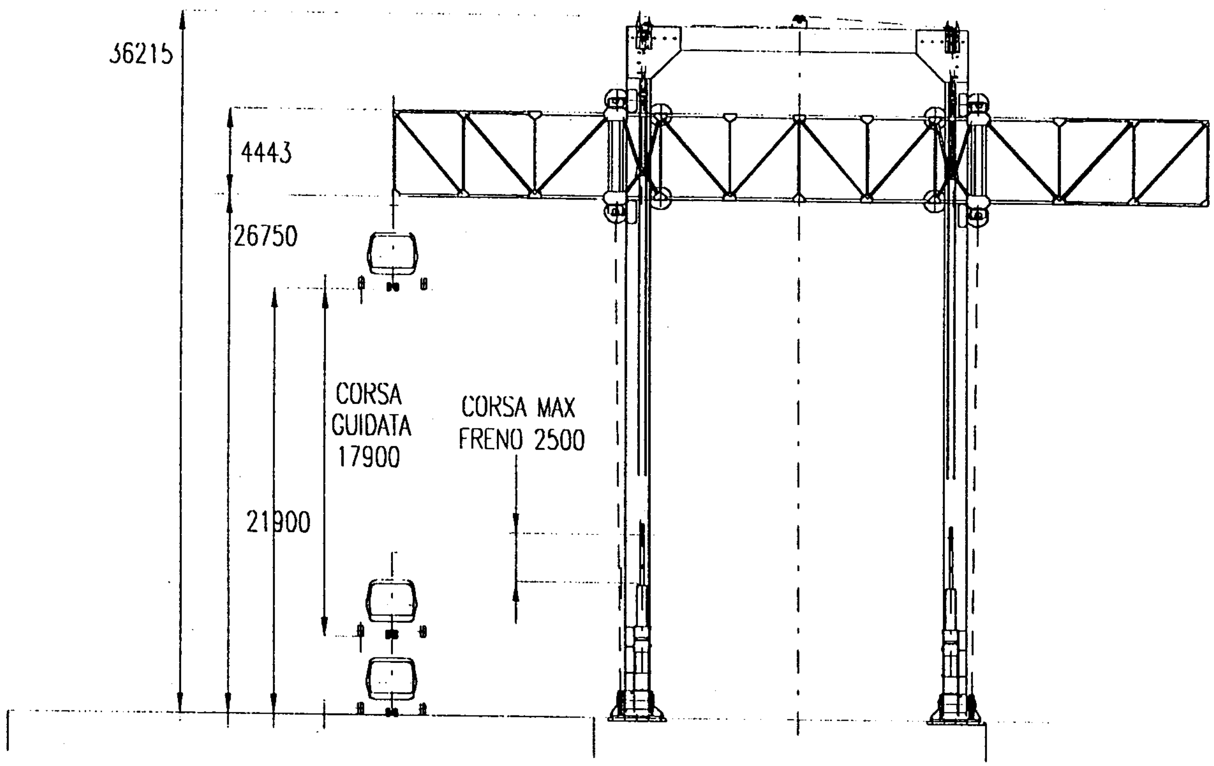
CIRA decided to start the LISA Project

LISA 's project guidelines

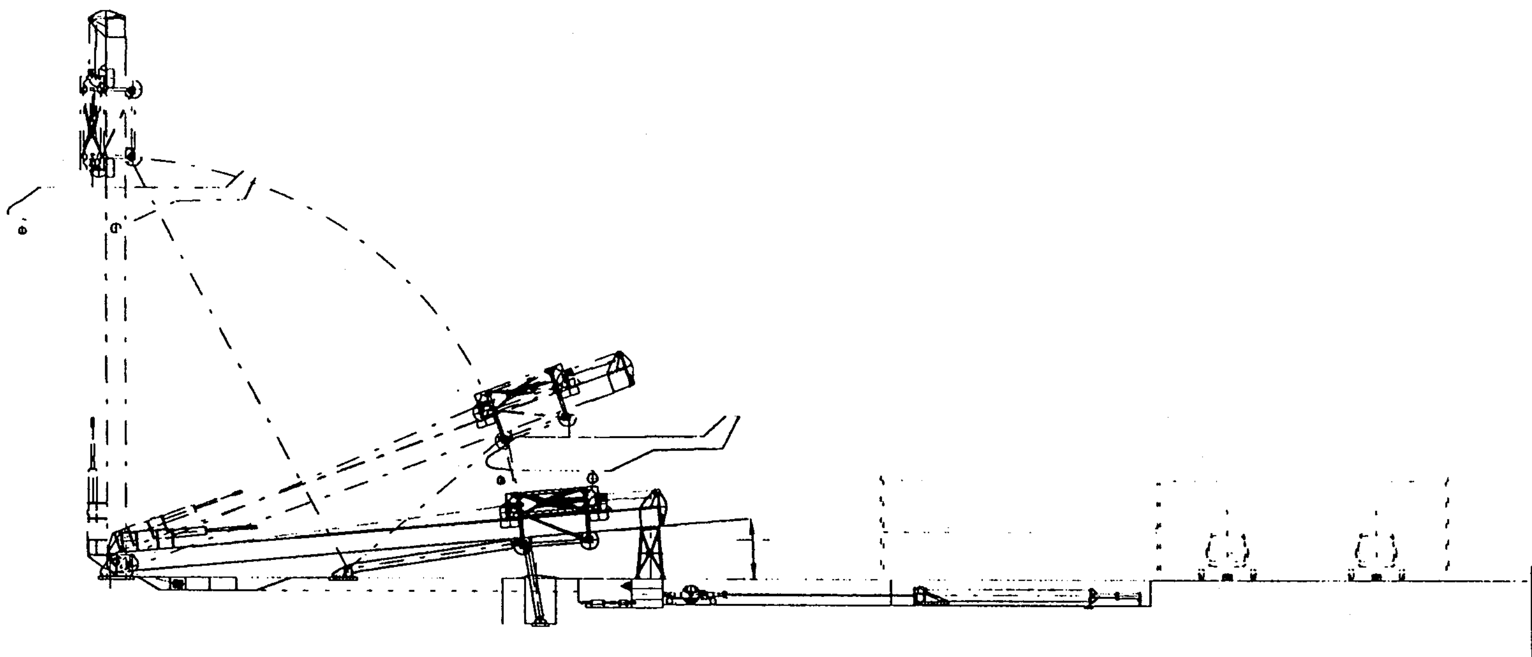
The design guidelines are defined in order to allow:

- ***Execution of Crash Tests on Complete Structures/Big size components (Up to about 15 t, max. impact speed 20 m/sec.)***
- ***Accurate Energy prediction and measurement***
- ***Any impact angle from 5° to 90°(vertical), accurate Trajectory and vehicle attitude***
- ***Impact on Solid (Concrete runway) and "Soft" ground and in Water.***
- ***Ditching and Emergency Landing on "Soft" ground.***

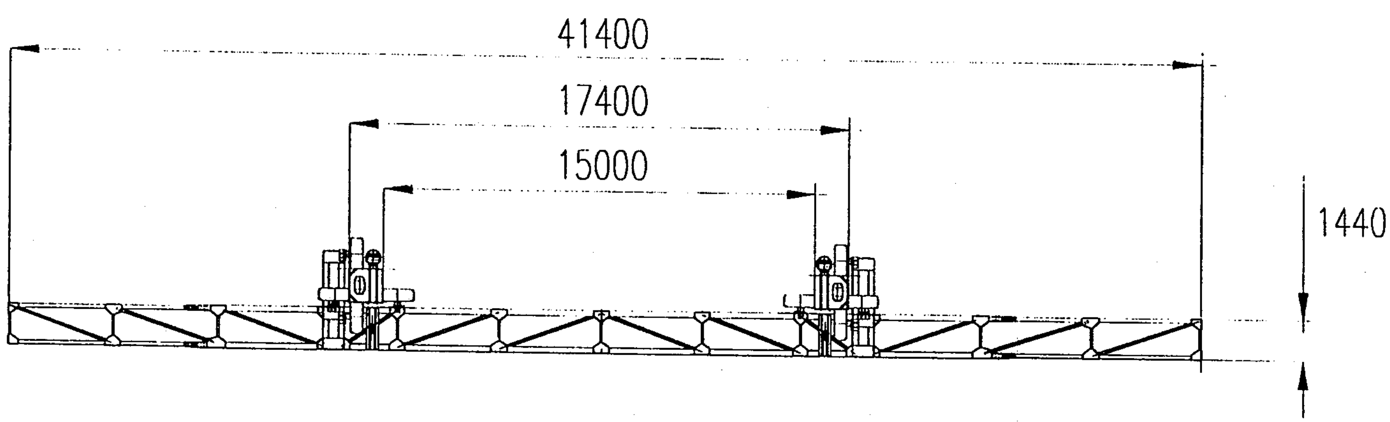
The facility shall be completed with a Crash-proof Data Acquisition System and high speed cameras for the structural collapse documentation and analysis.



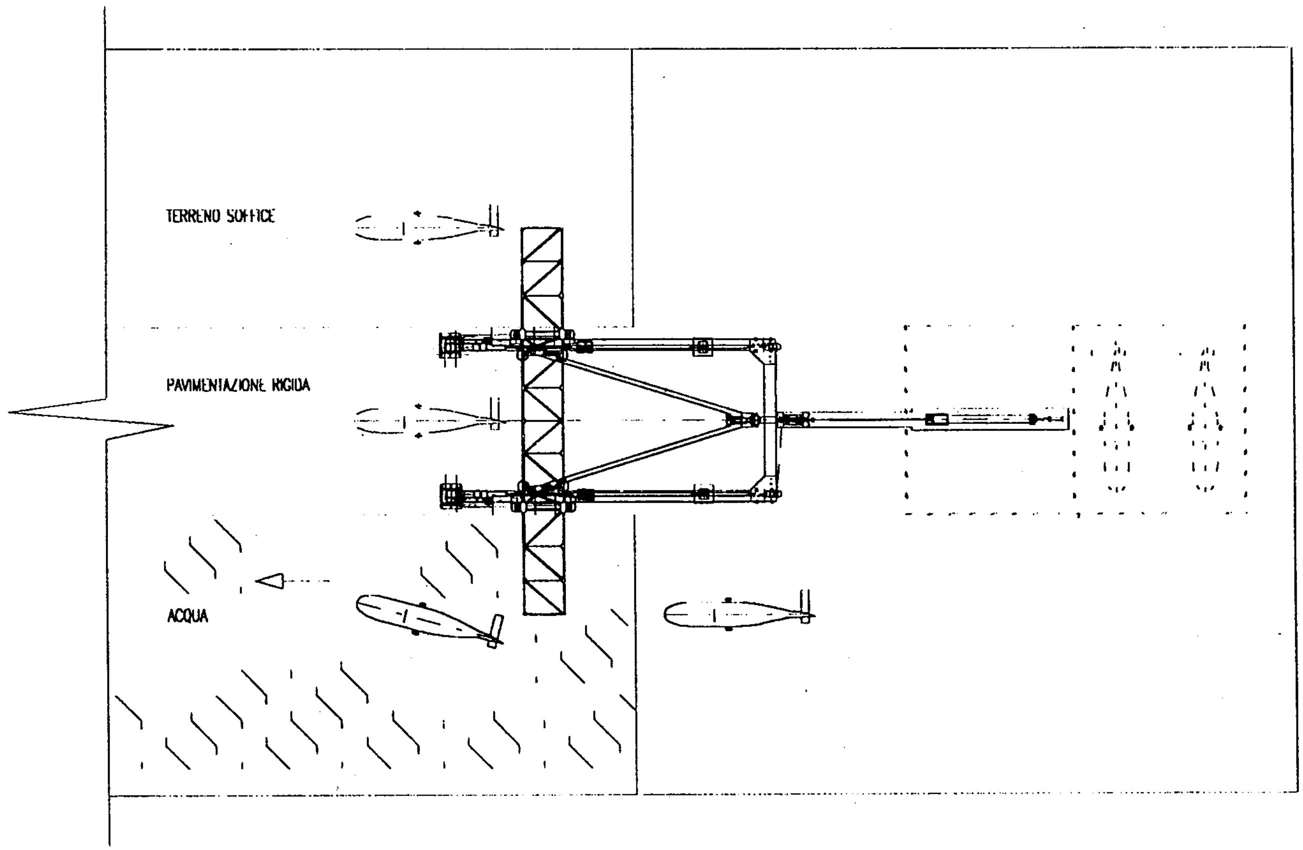
Front view of the LISA facility



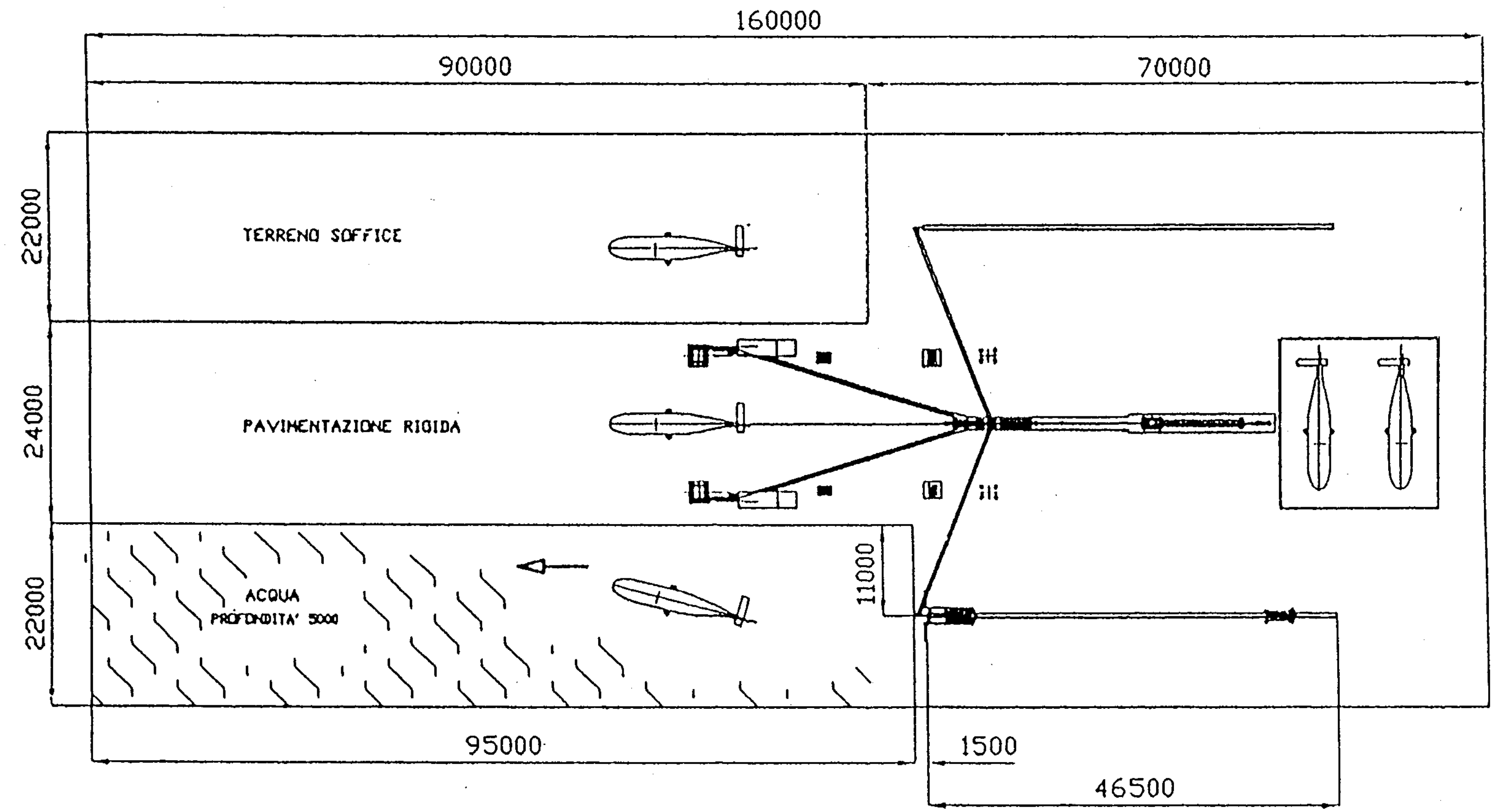
Lateral view of the LISA facility



Top view of the acceleration support carriage



Top view of the LISA facility



Rails for the Ditching Device

Basic Specification of the LISA LCTF

Vehicle Mass	*Up to 20000 kg in the most favourable test condition* *up to 10000 kg in the most critical test condition*
Impact Angle	*from 5° to 90°*
Impact Velocity	*Up to 20 ms^{-1}, at any angle*
Vehicle Attitude	*Potentially no limits*

Accuracy

velocity	± 0.2 ms^{-1}
impact angle	± 0.5°
vehicle attitude	± 1°

Basic Specification of the LISA LCTF (cont.)

Impact surface		*hard smooth concrete (runway like)* *"soft" ground (grass or ploughed)* *water (6 m deep without or with waves)*
Data acquisition		
	facility	*all parameters relevant to the operations* *(i.e. accelerations, velocities, strokes, pressures, etc.)*
	on board	*Crash-proof Digital Data Acquisition system (200Ch.),* *acceleration meters, strain gauges, load cells*
	on ground	*High velocity film and / or TV cameras*

Description & general Lay-out

- ***The Test Article (T.A.) is rigidly guided during the acceleration path by a wide carriage sliding along the sides of a large portal***
- ***The portal elevation (consequently the path) can be adjusted to the required angle***
- ***The test article can be projected on three different surfaces***
- ***A pneumatic ram, when needed, helps carriage acceleration***
- ***Hydro-pneumatic brakes decelerate the carriage after T.A. release***

Description & general Lay-out (cont.)

- ***The elevation of the portal is adjusted to the required angle by two pairs of hydraulic double effect rams***
- ***The carriage is lifted to the required height by a single winch acting on both sides of the portal***
- ***The release of the carriage is obtained by the synchronised opening of two hooks connecting the lifting cables to the carriage***
  In case of use of the acceleration pneumatic ram, the acceleration device itself acts on the hooks, starting the test.
- ***The T.A. is released from the carriage by explosive bolts before the start braking point, a "fusible" is foreseen in order to release the T.A. anyway at the beginning of the deceleration***

Other features

During the Configuration Design phase it was highlighted the possibility to widen the field of applicability of the LISA facility to the simulation of ***Ditching*** *and* ***Emergency Landing*** *the simple modification are:*

- ***Both the sides of the facility field will be equipped with horizontal rails .with appropriate "Brakes" equipments at the end***
- ***A carriage, sliding on these rails, shall drive the Test Article up to 30ms-1 (acceleration is supplied by a pull cable actuated by the pneumatic ram)***
- ***In the future the water pool should be equipped with a "Wave generation System" (up to 1m height waves could be produced)***

Specification of the LISA LCTF - Ditching & Emergency Landing

Max T.A. Mass .... *Up to 1000 kg*

Max T.A. Wing Span .... *Up to 7.5 m*

Ditching Velocity .... *Up to 30 ms^{-1}*

Trajectory Angle .... *-1° to 1°*

Sea state simulation capability

Safety & Reliability

The operation of the facility is rather complex and very delicate:

- ***Many systems shall work properly all together in a very short time***
- ***Safety of the personnel working in the facility is a major concern***
- ***The cost of a test may be very high, mainly due to the T. A. wich can be used only once***
- ***A possible failure in some system must not jeopardize the facility nor the T. A.***

All this demands for a very careful ***Safety and Reliability Plan***

Safety & Reliability (cont.)

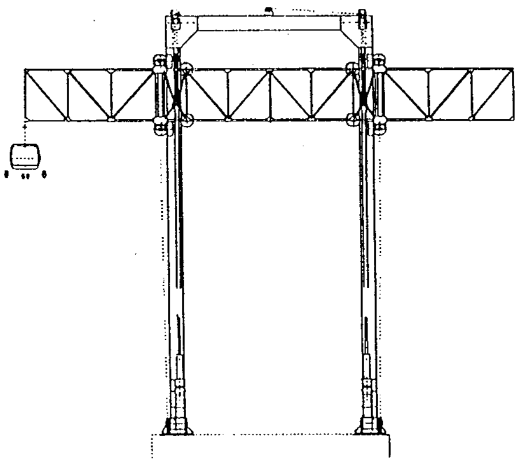
The plan was started with the project and include:

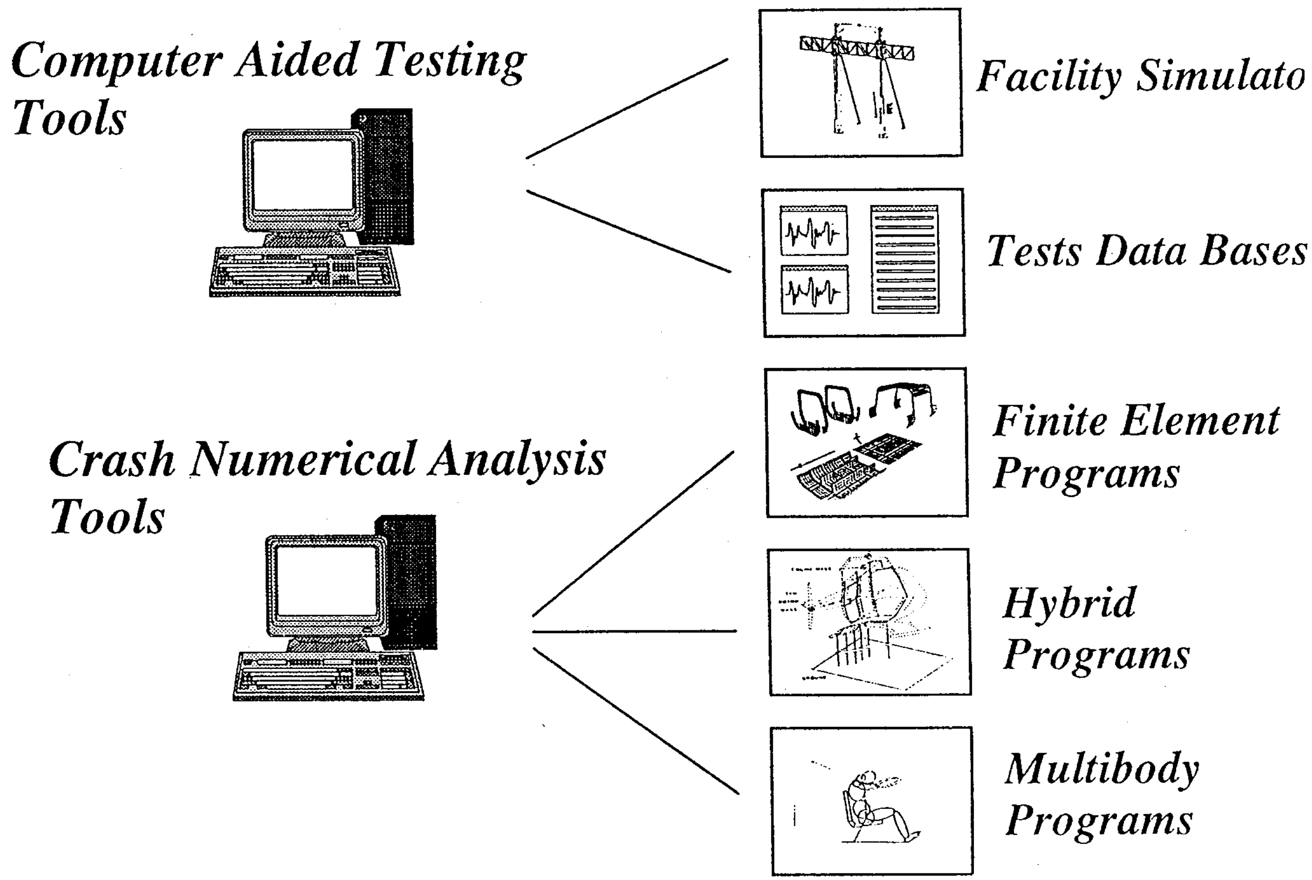
Monitoring	*The complete and continous check of the facility (also for the preventive maintenance)*
Safety Systems	*Inherent safe design, redundancy and "safe stop" of operations in case of failure.*
Safety manuals	*Implementation of safety rules and procedures and personnel formation*
Count Down Check list	*An accurate check list with all the actions, checks and colibrations, containing clear remarks to their links, and clearly identified time check-points shall be included in any Test Plan*

Principal milestones of LISA project

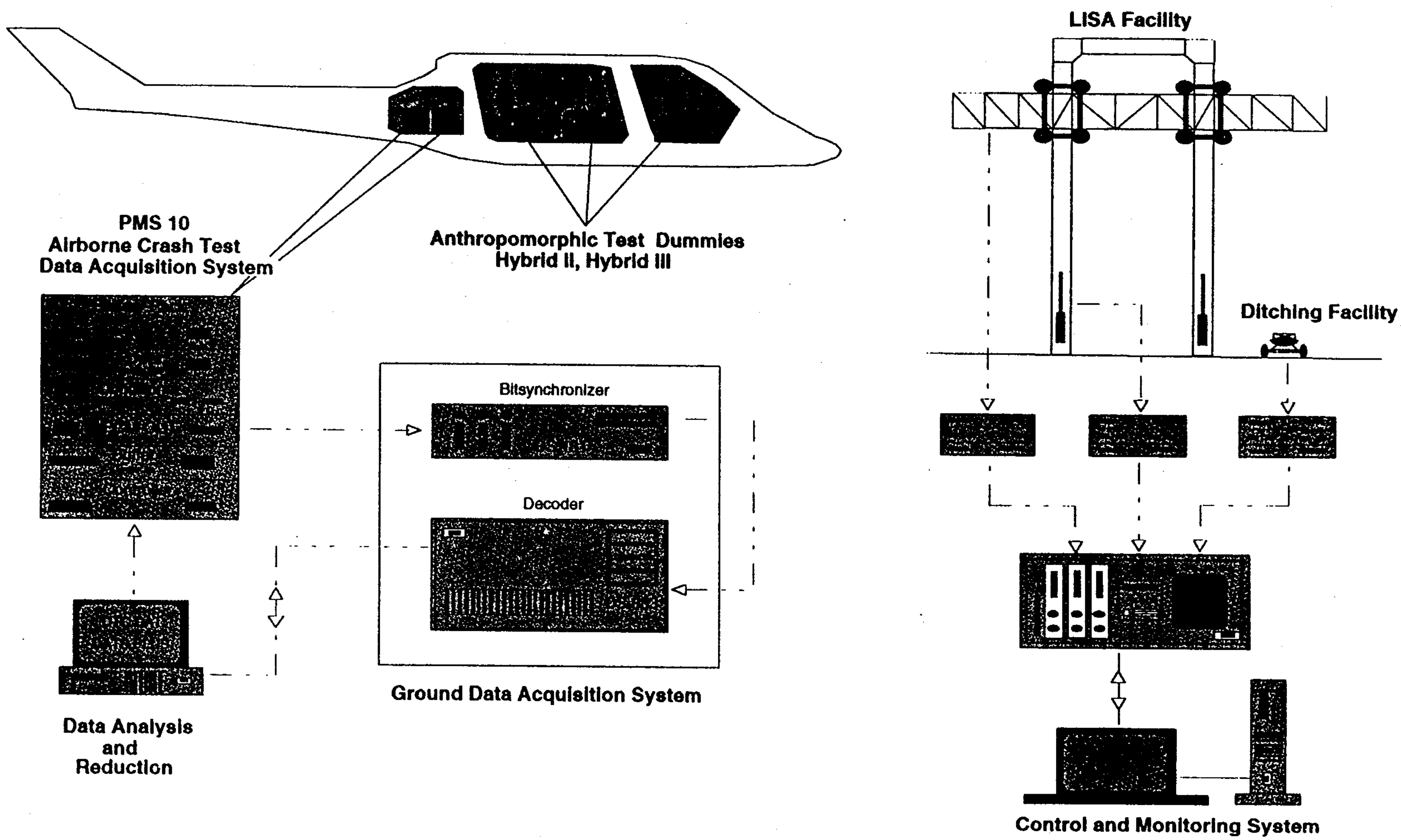
by may '95:	LISA configuration frozen
july '95 - april '96:	LISA developing phase
may '96 - december '96:	Civil plant building
may '96 - february '97:	Mechanical components manufactoring
march '97- june '97:	LISA plant assembling and integration
by the end of '97 :	LISA operational

LISA LCTF - NUMERICAL TOOLS





Hardware:
- *2 SGI Indigo2 R8000*
- *Convex C3860 - 6x120 MFLOPS*



DAS and Control - Monitoring System Block Diagram

Falcon 10 crash test presentation

Stéphane DEHARVENGT

DGAC
French Civil Aviation Authority

The different partners

- Sponsorship : DGAC
- Management : STPA/N
  (Technical services) DGA
- Contractors :
  - CEAT
    (Toulouse Aeronautical Test Center) DGA
  - DASSAULT AVIATION

The objectives

- To validate a crash computation model for small FAR/JAR 25 aircraft
- To evaluate the adequation of required dynamic test landing standards
- To propose rulemaking adapted to business jet

The milestones of the study

- The crash test performed at CEAT in 93
- The technical report of the test published in April 95
- The report on the recalibrated crash computation model published by Dassault in October 95

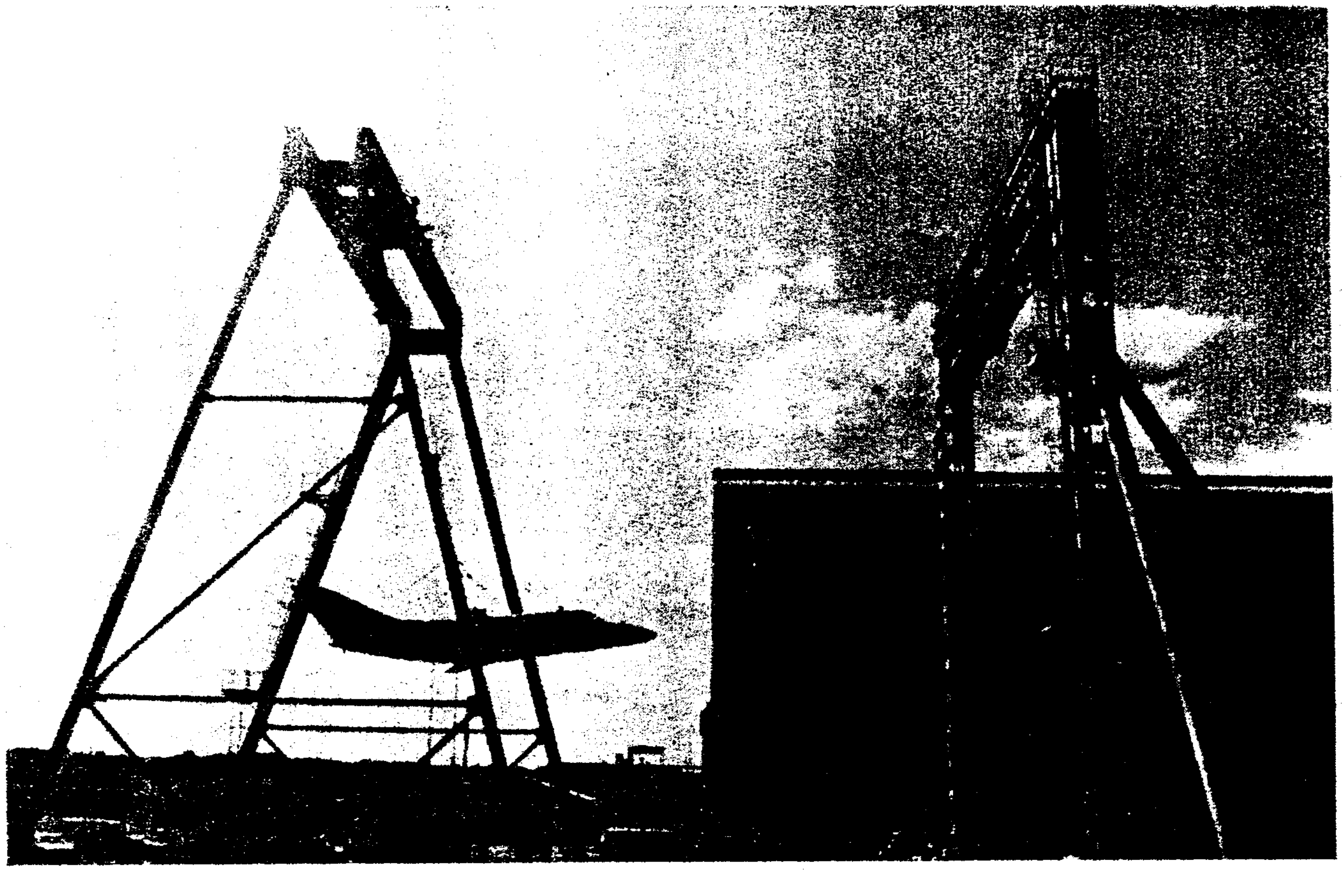
The test facility

MINISTERE DE LA DEFENSE

DGA

DIRECTION
DES CONSTRUCTIONS
AERONAUTIQUES

CENTRE D'ESSAIS
AERONAUTIQUE
DE TOULOUSE



The test article

DGA

DIRECTION
DES CONSTRUCTIONS
AERONAUTIQUES

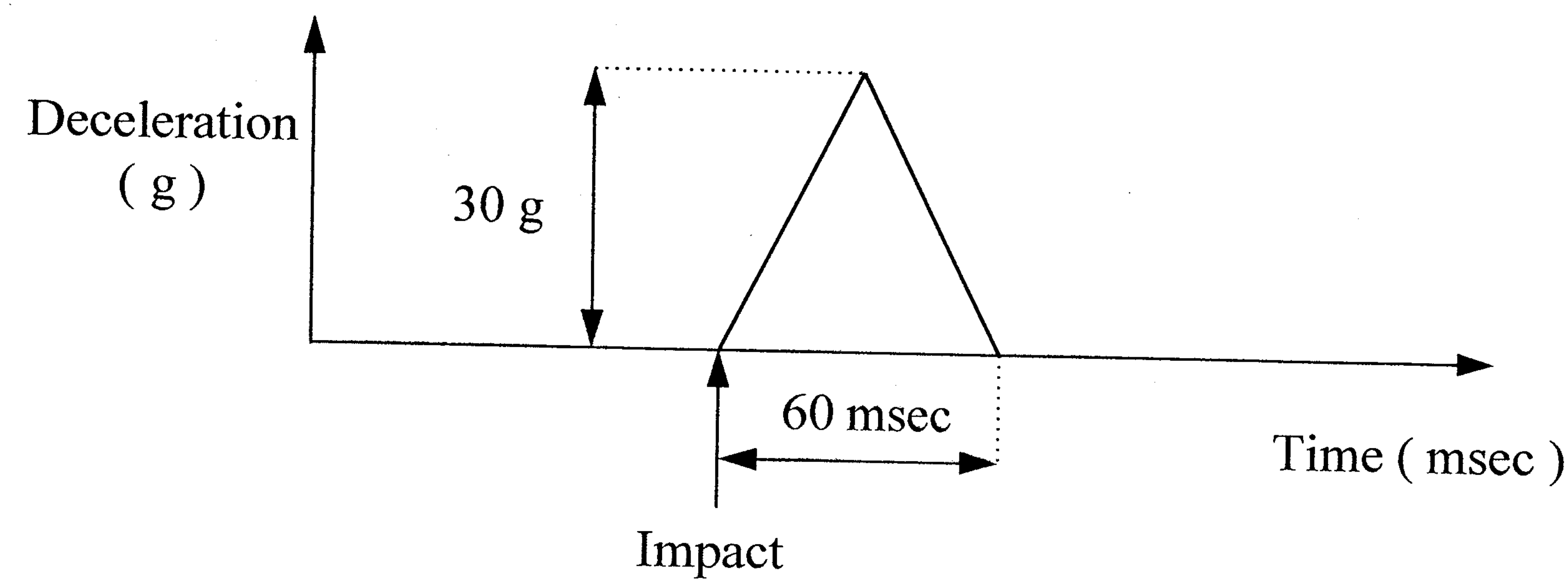
CENTRE D'ESSAIS
AERONAUTIQUE
DE TOULOUSE

Test description

- Test article : Dassault Falcon 10
- Scenario of the crash :
  - Emergency landing after take-off
  - Aircraft weight : 17 600 lbs (8 000 kg)
  - Swing test :
    - Height : 14,6 m (48 ft)
    - Vertical speed : 6,9 m/sec (22,6 ft/sec)
    - Horizontal speed : 14,7 m/sec (48,2 ft/sec)

The results of the test

- Average values for seats deceleration



The results of the test

- Crash test dummies response
  - Acceptable head and femur injury criteria
  - Positive results for CAMI designed seat
  - Efficiency of harness
  - Advantage of rear facing configuration

Future work

- Physiological analysis of the dummies response
- Analysis of the crash computation model report
- Proposal of rulemaking evolution

Conclusion

- First swing test in Europe
- Successful cooperation with the FAA
- Illustration of French research program orientations
  - to reduce the costs of certification compliance
  - to improve safety through risk/benefit analysis

FIRE SAFETY SESSION

Wednesday, November 15, 1995

Session Chairman
Jeff Gardlin
FAA, Aircraft Certification Service

FUTURE FIRE SAFETY R&D

Constantine P. Sarkos
Fire Safety Section
FAA Technical Center

International Conference on Cabin Safety Research
November 14-16, 1995
Harrah's Casino-Hotel
Atlantic City, NJ USA

Future Fire Safety R&D

Constantine P. Sarkos

Fire Safety Section
Federal Aviation Administration
Atlantic City International Airport, NJ 08405, USA

ABSTRACT

This paper will discuss current and future R&D under the FAA's Aircraft Systems Fire Safety Program. The fire safety program is near term and application oriented, relying almost entirely on FAA's in-house testing capabilities to develop fire safety improvements. Traditionally, this program has focused on transport aircraft interiors, including the cabin and cargo compartment. Current and future R&D direction and support is influenced by a number of factors, most notably accident experience, but also fire safety concerns associated with new aircraft designs or new technology, and past regulatory activities/interior design changes. The highest priority project under the current program is the development of certification criteria for halon replacement agents. On-going activities also include improving the resistance of the fuselage to burnthrough by a fuel fire and solving various problems related to existing FAA material fire test standards. Future R&D under this program will address areas of concern in future aircraft designs, such as the vulnerability of the upper deck in very large transports and the fire hazards of the composite fuselage skin in high speed civil transports. The need for future R&D in the following areas will also be discussed: oxygen and hydraulic systems fire safety, smoke detector reliability and testing standardization, impact of service wear and contamination on material flammability, lavatory fire protection and electrical wiring.

INTRODUCTION

The purpose of this paper is to describe the future direction of R&D conducted under the FAA's Aircraft Systems Fire Safety Program. The paper will discuss R&D currently under way and future R&D that is planned or proposed over the next 5-10 years. It should be recognized that the fire safety program is near term and application oriented. Specific fire problems are characterized and improvements are developed by conducting fire tests in the unique fire test facilities housed at the FAA Technical Center. Individual projects or activities are completed relatively quickly (near term) because of the availability of dedicated facilities and in-house expertise. The products of this research are utilized by FAA certification officials as regulatory or advisory material to improve aircraft fire safety. Over the years the primary application has been the interior of transport aircraft, mainly the cabin and cargo compartments.

The fire safety program is not a basic research program. Long range, fundamental research related to aircraft fire safety is conducted separately under the Fire Research Program, where the primary emphasis is on the development of ultra-fire resistant interior materials. Moreover, the responsibility for improving postcrash fuel containment on transport aircraft rests with another program, Propulsion and Fuel Systems. A complete description of aviation research programs undertaken by FAA is contained in the FAA Plan for Research, Engineering and Development (FAA, 1994).

PAST ACCOMPLISHMENTS

From 1984 to 1991, an unprecedented series of fire safety regulations adopted by FAA, that were primarily products of the Aircraft Systems Fire Safety Program (Sarkos, 1989), were implemented at great cost by the aircraft manufacturers and airlines. The regulations were aimed at improving survivability during postcrash fires and preventing uncontrollable in-flight fires. A summary of the standards specifically attributed to the fire safety program follows.

Postcrash Fire

Seat Cushion Fire Blocking Layers. This rule requires that seat cushions meet a severe flammability test that simulates a postcrash fire. The standard reduces the burning rate and involvement of the flammable (albeit fire retardant) urethane foam during a severe cabin fire. Most US airlines encapsulate the urethane foam with a highly fire resistant fire blocking layer material.

Low Heat/Smoke Release Panels. This rule requires that large surface area panels (sidewalls, ceiling, stowage bins and partitions) meet a stringent heat release test. Airframe manufacturers were required to develop new material designs in order to gain compliance with the standard. In this sense, the standard was considered to be a technology driver.

Floor Proximity Lighting. This rule requires that airplane emergency lighting systems provide escape path (aisle) definition and identify each exit when smoke accumulates in the upper cabin and obscures overhead lights.

Radiant Heat Resistant Slides. This revised Technical Standard Order (TSO) includes a new test requirement that measures the heat resistance of pressurized slide material. Evacuation slides constructed of reflective materials compliant with this test remain inflated much longer when subjected to fuel fire radiative heating during an emergency evacuation..

In-Flight Fire

Halon 1211 Extinguishers. This rule requires at least two Halon 1211 hand-held extinguishers in every transport airplane. The requirement was based on the demonstrated superior fire knockdown capabilities and low toxicity of Halon 1211.

Burnthrough Resistant Cargo Liners. This rule requires a severe burnthrough test for ceiling and sidewall cargo liners in inaccessible cargo compartments. Cargo liners compliant with this test will prevent cargo/baggage fires from spreading outside the cargo compartment, maintaining flight control and protecting passengers and crewmembers.

Additionally, since 1991 rulemaking activities related to cargo compartment fire protection and flight recorder postcrash fire survivability were supported by the Aircraft Systems Fire Safety Program. An airworthiness directive, issued April 20, 1993, to ensure adequate fire protection in "combi" aircraft, contains provisions based on full-scale fire tests (FAA, 1993a). Also, new fire protection requirements for accessible cargo compartments in small airplanes are being developed because fire tests showed manual firefighting by flight attendants was ineffective and potentially dangerous. Finally, based in part on completed testing (Curran, 1993), FAA is developing a new TSO for flight recorders which will include new fire test criteria aimed at assuring greater recorder survivability in accidents accompanied by postcrash fire.

R&D DRIVERS

The direction and level of support for the fire safety program is influenced by a number of factors, most notably accident experience, but also the effect of past regulatory activities/interior design changes and fire safety concerns associated with new aircraft designs or technology. The greatest determinant is, understandably, recent accident experience. In times of budget constraint, scarce resources are often devoted to R&D programs addressing a problem area punctuated by recent accident experience. In recent years funding available to the Aircraft Systems Fire Safety Program has decreased. Less people are also dying from fire in aircraft accidents as indicated in Figure 1, which shows worldwide fire fatalities per million flying hours over a 30 year period (CAA, 1993). Interestingly, Figure 1 may be interpreted to support opposing positions. Certainly, the record is far better now as compared to 15-20 years ago. Also, there seems to be an improving trend which is somewhat coincident with the mandated fire safety improvements, described earlier, implemented from 1984-1991. Conversely, one may argue that the fire safety improvements have bottomed out and as traffic increases in the future the number of fire fatalities will rise. Also, as we have observed in the past, there is always the possibility of a bad accident with a high number of fire fatalities in spite of improving trends.

Another factor which has an important bearing on the fire safety program is past regulatory activity that has lead to the installation of a number of fire safety improvements in the US fleet, as discussed earlier (Sarkos, 1989). For example, 650,000 seats were protected with fire blocking layers at a cost of $75 million to US airlines. The airlines and airframe manufacturers have also invested several $100 million in low heat/smoke release panels. Thus, using these examples, it is clear that the aviation industry has made a significant financial investment toward the improvement of aircraft fire safety, and based on the recent accident record, it appears as if this investment has paid off. Furthermore, the cost/benefit ratio of potential new fire safety improvements (e.g., cabin water spray) becomes exceedingly large (unfavorable) when factoring in the effect of lower fire fatalities and the benefit of past improvements.

Fire Safety considerations in new aircraft designs, including the Very Large Commercial Transport (VLCT) and High Speed Civil Transport (HSCT), will be addressed in future R&D under the fire safety program. The vulnerability of the upper deck in the VLCT and the impact on postcrash survivability is a major concern. Industry and government officials appear in agreement that carrying 800 - 1000 passengers, the VLCT must be designed to higher fire safety standards than contemporary airliners (Aviation Week and Space Technology, 1984). This attitude is not unprecedented. Tougher fire safety and emergency evacuation design criteria were imposed on the wide body jets when they were introduced into service in the early 1970's. With respect to the supersonic HSCT, the possibility of a composite fuselage skin raises a general question. Will the replacement of the non-combustible aluminum skin with an organic composite material impact HSCT postcrash fire survivability?

FUTURE FIRE SAFETY R&D

It is useful to partition the discussion of future R&D under the Aircraft Systems Fire Safety Program in terms of the program's three major areas - Materials, Fire Management and Systems. Materials consists of the development of improved or new fire test methods and criteria for aircraft materials. Fire management refers to rapid and reliable detection of aircraft fires and effective fire extinguishment or suppression. Systems addresses the need for the protection of

vital aircraft systems from the effects of fire or preventing malfunction of these systems from causing or accelerating the spread of a fire.

Materials

There is general agreement that significant gains in postcrash fire survivability were achieved by seat cushion fire blocking layers and low heat/smoke release panels. Seat cushions, particularly urethane foam, and large surface area panels (sidewalls, ceiling, stowage bins and partitions) are clearly the most important interior material categories with respect to the generation of postcrash cabin fire hazards. The FAA standards mandating these material upgrades were developed for a cabin fire scenario consisting of an external fuel fire adjacent to a fuselage opening; i.e., interior materials are directly exposed to the fuel fire. Further improvements in postcrash fire safety would be expected to be minimal from additional incremental gains in seat cushion or panel fire test performance. Also, although there are other material categories such as seat components or transparencies that should be studied to determine if improved testing standards would increase safety, full-scale tests on seat components have indicated that this is not the case. At this time, in terms of postcrash cabin fire material performance, FAA R&D is long term in nature, under the Fire Research Program, and aimed at the development of ultra-fire resistant (practically fire proof) interior materials.

Fuselage Burnthrough. In approximately 50% of survivable postcrash fire accidents, the fuselage remains intact and the cabin is ignited by the external fuel fire burning through the fuselage shell. The most catastrophic example of this type of postcrash fire scenario was the 737 accident in Manchester, England (Aircraft Accidents Investigation Branch, 1988). Investigators concluded that the fuel fire penetrated the fuselage in approximately 60 seconds. Although there was no impact trauma, 55 people died from the effects of the cabin fire. The Air Accidents Investigation Branch recommended "increased effort directed towards fire hardening of the hull, the limitation of fire transmission through the structure" ....leading to "fire criteria should form a part of international airworthiness requirements". FAA has conducted full-scale fire tests to determine the mechanism and time framework for fuselage burnthrough (Webster, 1994). It appears that the lower quadrant or cheek area is most vulnerable to burnthrough due at least to the lesser thickness of thermal insulation in this area. Fire and smoke penetration into the cabin is initially via air return grilles and sidewall panel edging. FAA has a cooperative program with the U.K. Civil Aviation Authority to evaluate new materials and concepts for hardening a fuselage against burnthrough. Target areas include the insulative properties of the thermal acoustical insulation, installation and fastening features of the insulation, and possibly, intumescent paints or gates to prevent flame entry through air return grilles. If this endeavor is successful it would lead to development of design guidelines.

The planned use of composite material for the fuselage skin in the high speed civil transport (HSCT) is another concern. Conventional aluminum skin conducts heat away and melts rather quickly when exposed to a fuel fire, whereas a composite skin will char and probably be an effective fire barrier. The concern is whether pyrolysis products in the form of smoke and toxic/combustible gases percolate through the composite, creating hazardous conditions within the cabin. This issue needs to be addressed during the early stage of the HSCT design.

In-flight Fires. The types of in-flight fire that can become a problem are those that originate in hidden or inaccessible areas. Upgraded seat cushion and panel fire test standards to enhance postcrash fire survivability were not developed to address the hidden in-flight fire scenario. Hidden fires involve materials such as thermal acoustical insulation, wiring and cable, installed behind the cabin sidewall, above the ceiling and beneath the floor. Contamination is a

serious part of the problem. Past full-scale tests have shown that thermal acoustical insulation, when it is new and uncontaminated, will not propagate a fire initiated by a small ignition source (Blake, 1991). However, a number of hidden fires have occurred in-flight or on the ground which, in some cases, have gutted the aircraft. Investigation of these fires have revealed extensive contamination in hidden areas, for example, thick greasy dust on cable, stained insulation batt, grease, etc. Work is needed to address the contamination problem in hidden areas.

Most aircraft in-flight fires are electrical in nature and are usually controlled before having any effect on flight safety. At present, the only standard for aircraft wiring is a Bunsen burner flammability test. However, arc tracking failures have occurred in civilian and military aircraft. Also, electrical fires may cause high cockpit smoke levels; yet wiring selection in civil transports is not based on smoke emission. Finally, electrical faults from frayed wires have occurred in service because of failed or improper securing of wiring and cable. Therefore, more comprehensive test methods are required for electrical wiring as well as improved methods for securing and protecting cable and wiring.

Fire Management

Although more fireworthy interior materials have improved aircraft fire safety, risk of fire is also posed by other contents of the airplane. These include fuel, freight and luggage in the cargo compartments, passenger carry-ons, hydraulic fluid, and emergency oxygen systems. Fire management employs active systems to counter these potential fire hazards.

Halon Replacement Guidelines. For the past 35 years, the agent of choice in aircraft fire extinguishing systems has been Halon 1301. Unfortunately, on December 31, 1993, the manufacturer of halons ceased by international agreement because of their contribution to the depletion of the ozone layer. The uncertain future availability of halons for aircraft fire extinguishment systems is the highest priority concern of FAA's fire safety R&D program. A description of the halon replacement project is contained in the Public Notice published in the Federal Register (FAA, 1993b). For the next several years, FAA will be working closely with the aviation industry to evaluate promising new agents under full-scale fire test conditions and to develop the basis for demonstrating equivalent fire protection with halon for aircraft applications; viz., cargo compartments, engine nacelles, hand-held extinguishers and lavatory trash receptacles.

Cabin Water Spray. An approach for increasing postcrash fire survivability against all fire sources, including burning jet fuel, is an on-board water spray system. For several years FAA has worked with CAA and Transport Canada to test and develop a cabin water spray system. The initial system tested, developed in England by a company named SAVE, continually sprayed water throughout the cabin for about three minutes. In numerous full-scale fire tests employing wide body, standard body and commuter aircraft test articles, and over a range of fire scenarios it was shown that water spray increased survival time by 2-3 minutes for all but the most unusually severe fire condition. Moreover, a zoned system was developed and optimized that actually provided more protection than the original system, but only used 10% of the water (Sarkos, et al., 1995). Poor cost-effectiveness of water spray, due largely to the relatively small number of fire fatalities in recent years, makes it unacceptable for service consideration at this time. FAA is now evaluating the effectiveness of water spray against cargo fires, as a halon alternative and as a possible means of offsetting the weight penalty of the cabin water spray system. Cabin water spray will also be evaluated for future aircraft designs, where the cost/benefit may be more favorable.

Fire Detection. Reliable and rapid detection of fire and smoke is critical to the effectiveness of intervention systems and procedures. It has been estimated that 90% of cargo compartment smoke detector activations are false alarms. Also, although FAR 25.858 states a cargo compartment fire detection system "must provide a visual indication to the flight crew within one minute after the start of a fire", there are currently no standardized test procedures to demonstrate compliance with this rule. It is possible that the responsiveness to realistic fires varies for different FAA-approved smoke detection systems. For example, past FAA fire tests demonstrated that artificial smoke, used to certify smoke detectors, indicated a more rapid response time than real smoke in detector systems employing vacuum sampling lines (Blake 1985). Thus, a need exists for more reliable smoke detection systems and standardized test procedures for the certification of aircraft smoke detectors.

Lavatory Fire Protection. Lavatories have been the source of several fatal in-flight fires (Varig, 1973; Air Canada, 1983), accounting for 146 fire fatalities. These accidents were the impetus for important improvements in lavatory fire protection, such as a cigarette smoking ban, fire hardening of trash receptacles, halon extinguishers ("potty bottles") and smoke detectors. Nevertheless, serious lavatory fires continue to occur. In 1993, an in-flight fire in the aft lavatory of a Domincana 727 forced an emergency landing. All occupants escaped but the fire spread out of control and destroyed the aircraft. The accident highlighted deficiencies in crew procedures in locating and extinguishing in-flight fires; e.g., hand-held extinguishers were readied but never discharged. In 1995, an International Airlines DC-9 was gutted by fire while parked at a ramp in Barranquilla, Columbia. Investigators notes similarities between this unattended ramp fire and the Air Canada in-flight fire in 1983. These recent fires raise concerns about the adequacy of lavatory fire protection. The presence of potential ignition sources such as flushing motors, hot water heaters, lighting ballasts, and razor outlets reported instances of improper passenger activity (detector tampering, smoking, etc.), and certain design features, such as high ventilation rates that may circumvent early fire detection, all point to the need for R&D to enhance fire protection design and crew firefighting procedures in aircraft lavatories.

Aerosol Cans. A relatively unrecognized potential fire safety hazard is the large number of aerosol cans carried in passenger luggage. Since 1979, aerosol cans have employed flammable hydrocarbon propellants including propane, butane and isobutane to replace the ozone depleting chlorofluorocarbons (CFC's). Conventional, three-piece aerosol cans burst and rocket when exposed to a fire. The remnants of discharged aerosol cans have been found in the contents of burned-out aircraft involved in a fire accident or incident; although it has been difficult to establish what role the aerosol cans played in the fire. From full-scale fire tests, however, it is known that bursting aerosol cans release their hydrocarbon propellants, increasing the fire growth rate and, more importantly, may create rocketing projectiles that dislodge or penetrate cargo liners, violating design principles for cargo fire containment and allowing the fire to spread to other areas of the airplane (Blake, 1989). The behavior of aerosol cans in cargo compartment test fires is not unprecedented; bursting cans are known to have broken through car trunks and windshields due to simply overheating by the hot sun. A safer aerosol can design has been developed under an FAA-funded Small Business Innovative Research (SBIR) study. The improved can withstands higher operating pressures and provides a mechanism for the controlled release of the can contents at elevated pressures (Daehn, 1994). Additional research is required to determine the benefit of improved aerosol cans during aircraft fires and to develop the design concept into a viable manufacturing process.

Very Large Commercial Transport. The vulnerability of the upper deck to postcrash fire in future double-decked aircraft carrying 800-1000 passengers such as the VLCT, is a major concern of aircraft manufacturers and regulatory authorities. The anticipated difficulty of exercising an emergency evacuation from high elevations would become even more life

threatening if a chimney-like effect created an unusually hazardous fire on the upper deck. Enhanced fire protection of the VLCT upper deck would tentatively encompass three R&D activities. First, is the development of fire stops and barriers to prevent upward spreading of the fire from the lower deck. All potential fire paths such as open stairways, elevators and uninterrupted channels between formers would require protective measures to prevent upward flame spread. Second, it is the protection of the upper deck floor from the effects of a fire from below. The strength of flooring and floor beams, especially of composite construction, must be adequate during the evacuation process to prevent floor collapse. Finally, enhanced fire protection of the upper cabin interior will likely weight the relative effectiveness of improved fire resistant materials against an on-board cabin water spray system.

Systems

The objective of the systems area of the fire safety program is to minimize or eliminate fire hazards associated with aircraft systems. Past accidents and full-scale tests indicate that improvements in oxygen and hydraulic systems could improve both postcrash and in-flight fire safety.

Oxygen Systems. There is an abundance of "pure" oxygen carried on-board commercial airliners. Oxygen systems include oxygen for use in the event of depressurization, oxygen for the flight deck crew, medical oxygen, and crew protective breathing devices for in-flight fire. Preventing fires caused by oxygen system malfunctions during servicing and maintenance will eliminate a significant number of hull losses alone. For example, inadvertent activation of an oxygen mask canister caused a fire that gutted a DC-10 in Chicago 1n 1986. Also, in Salt Lake City in 1989, replacement of an oxygen bottle during preboarding of a 727 caused an extremely intense fire that rapidly spread throughout the cabin. Fortunately, there were only a few occupants on board at the time and they were barely able to escape the fire that reached untenable conditions in an estimated 45 seconds. Also, in New Delhi in 1991, deployment of the passenger oxygen system during a maintenance check in a 737 caused an oxygen-fed fire in the vicinity of the pressure controller (Hill, 1994). The potential large loss of life due to an in-flight fire caused by oxygen system malfunction, similar to the above examples which occurred on the ground, or by a postcrash fire intensified by the release of oxygen is a great concern. Many of the 20 postcrash fire fatalities in the 737 accident at Los Angeles in 1991 may be attributed to the severed crew emergency oxygen system. FAA full-scale fire tests demonstrated a three minute loss of survival due to the release of oxygen into the postcrash fire (Marker and Downie, 1991). In the near term, methods of reducing the quantity of oxygen accidentally released should be explored; e.g., flow restrictors, fuses or solid oxygen generators. The ultimate answer may be an oxygen generation system utilizing gas separation membrane technology, which would probably require a long term R&D program.

Hydraulic Systems. Aircraft hydraulic fluid has been the source of both in-flight and postcrash fires. In 1989 a 737 experienced a hydraulic fluid fire in the wheel well that resulted in an emergency landing and evacuation. Although there were no fatalities, the ingredients of a catastrophic accident were present; i.e., the fire caused loss of hydraulic pressure and breaking action, causing the airplane to overrun the end of the runway. FAA tests showed that hydraulic fluid spray contained in a enclosure such as a wheel well, may burn intensely if ignited (Blake, 1990). In 1980, a 747 experienced a crash fire following a hard landing caused by the sparking ignition of hydraulic fluid released by damaged struts. Fifteen people died form the postcrash fire in which there was no jet fuel spillage. There is sometimes a misconception that fire resistant aviation hydraulic fluid is noncombustible, but this is obviously not the case. Near term

R&D is required to determine what improvements are feasible to prevent or minimize hydraulic fluid fires.

FINAL COMMENTARY

This paper describes future R&D activities under FAA's Aircraft Systems Fire Safety Program. The future program builds on past accomplishments which have resulted in significant gains in aircraft fire safety. Problem areas highlighted by accidents and incidents are the primary factor defining future R&D activities. Other factors such as the ban on halon production are also important. Anti-misting kerosene and smoke hoods - research activities familiar to the public - were not discussed because they fall under the purview of other FAA R&D programs. Similarly, long range, basic research is the responsibility of the Fire Research Program.

Each of the research activities identified in this paper has its own merit. Due to large reductions in Congressionally appropriated R&D funds and increasing competition amongst FAA safety programs for a diminishing R&D funding base, it is very difficult to predict which of the future R&D activities discussed in this paper will actually be funded. Over the next five years, it is likely that more will not be funded than will be funded.

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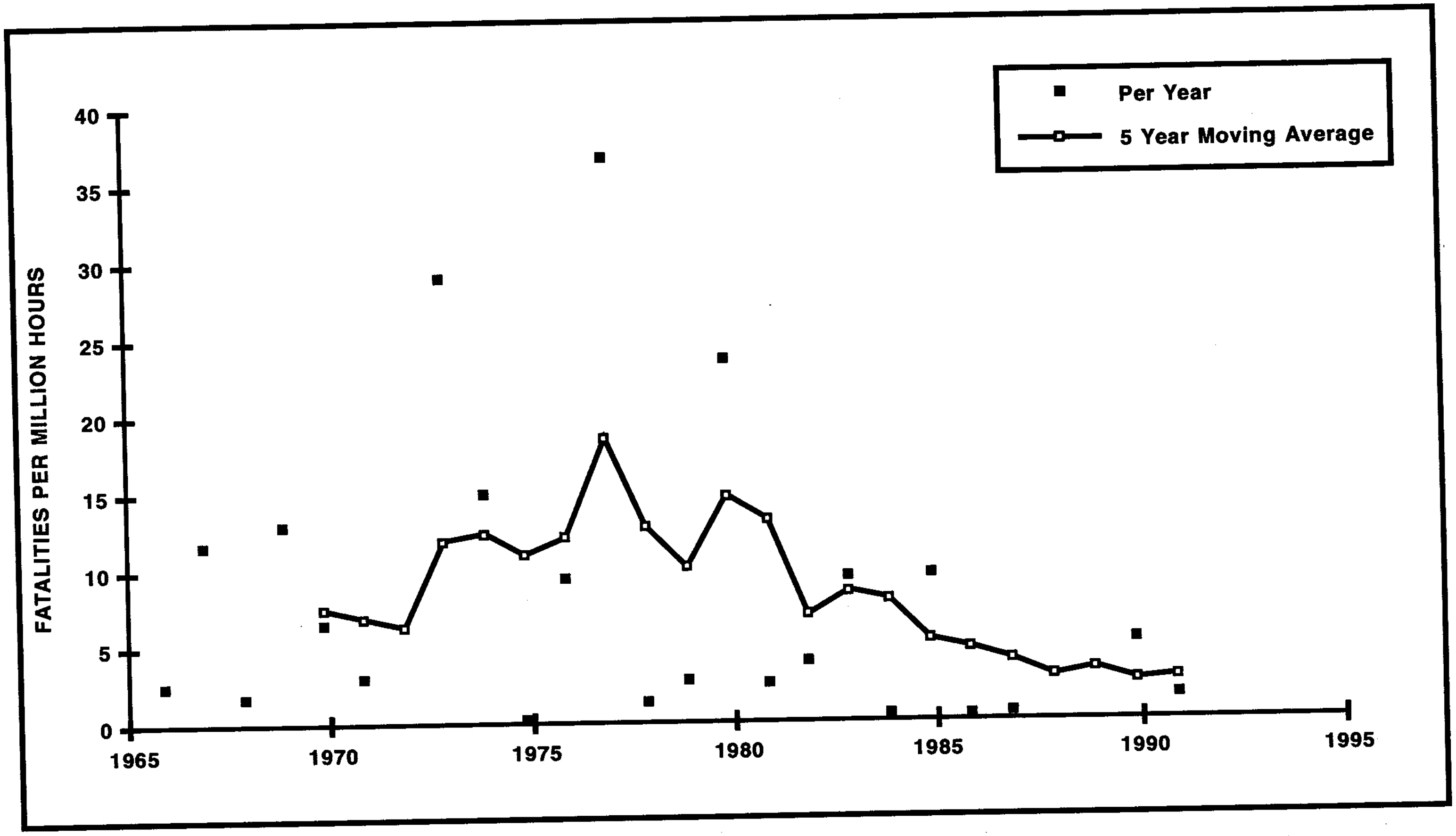

FIGURE 1. FATALITIES DUE TO FIRE PER MILLION FLYING HOURS IN WORLD-WIDE COMMERCIAL TRANSPORT ACCIDENTS (CAA, 1993)

Industry Perspective On What Is Needed In Fire Safety

Theo KLEMS
AIRBUS INDUSTRIE, TOULOUSE
ENGINEERING DIRECTORATE

ABSTRACT

With the predicted increase in world air traffic (doubling the fleet size by the year 2015), and the move towards bigger aircraft the fatalities caused by accidents with fire will increase more than proportionally. This increase would be unacceptable and is completely contrary to the regulatory requirement to reduce the absolute number of fatalities from the present number by at least 50%.

AIRBUS INDUSTRIE believes that the most effective aircraft safety philosophy is to "Prevent Accidents."

Long term research has been established already in this field.

In addition to these activities there is also a need for more research in passive aircraft safety addressing especially cabin fire safety by improved fuselage burnthrough characteristics and fire resistant interior materials.

This paper reflects the general perspective on aircraft safety as well as the specific industrial objectives on future fire safety.

INTRODUCTION

Fire safety is a very complex issue comprising safety systems as for e.g. smoke detection and fire extinguishing systems for lavatory waste bins, cargo compartments and engines as well as the wide range of fire resistant interior materials and furnishings.

The introduction of most of the aircraft safety regulations were based to the reaction on individual accidents and resulting technical problems.

In order to realize the most effective aircraft safety philosophy by preventing accidents there is a need for a more systematic research with regard to the relationship between growing complexity of aircraft systems and human effectiveness as well as focussing on human confrontation to abnormal situations during flight operation.
Besides this principle future safety research there are a number of concrete safety activities to be realized as for e.g. fuselage burnthrough resistance, improved fire/smoke detection and extinguishing systems, halon replacement, fuselage safety, fire resistant interior materials and fire containment technologies.

We have to recognize that more and more universities and institutes are supporting these activities by the introduction of computer programs and technologies for e.g. fire modeling and evacuation modeling in order to avoid expensive and risky full scale testings.

From the industrial point of view the ecological and economical aspects are very important parameters for future developments and have to be considered.

DRIVER FOR IMPROVED FIRE SAFETY

The worldwide demand for air travel will continue to grow strongly.

The Airbus Industrie Global Market Forecast (1995-2014) states that passenger traffic carried by the world's major airlines will almost triple growing at an average annual rate of 5,1%.

To renew their fleets as well as accommodate traffic growth, the world's airlines will take delivery of 15.000 new and used passenger aircraft. This total will include some 7.700 basically single-aisle types with fewer than 200 seats (51% of the total) and 7.300 wide-bodies (49%).

The capacity of the world's passenger fleet will more than double. Despite increase in passenger load factors and average aircraft productivity, the number of seats in the world jetliner fleet will grow from 1,6 million at end 1994 to 4 million at end 2014 in order to accommodate traffic growth.

An increasing proportion of the world passenger fleet will consist of wide-body aircraft. From just 28% today the proportion of wide-bodies will increase to 46% at end 2014.

A substantial requirement will develop for a new type of aircraft larger than anything flying today.

The overall result is a projected 20 year average annual growth of 1,5% in aircraft seating capacity and of 3,2% in flight frequency. This implies that the world airport and air traffic management system will be able to handle an 86% increase in flight frequencies by the end of the forecast period, while average aircraft seating increases by 34%.

Based on this predicted increase in world air traffic the fatalities caused by accidents with fire will increase more than proportionally. This would be unacceptable and is completely contrary to the regulatory requirement to reduce the absolute number of fatalities from the present number by at least 50%. In this context the improvement of aircraft fire safety will become a very important issue.

STATE OF THE ART

The present state of the art of aircraft/fire safety already represents a high standard.
The history of flammability requirement for cabin interior shows that flammability regulations were first adopted in 1947 with a requirement that cabin materials shall not burn greater than 10 cm in a horizontal orientation when exposed at one end to a bunsenburner flame.

The availability of improved fire resistant materials led to a permanent upgrading of the flammability regulations.

Milestones in fire safety are as follows :

1972	Bunsenburner	FAR	25.853	Amdt.	32
1984	Seat Cushion	FAR	25.853	Amdt.	59
1986	Burnthrough Cargo	FAR	25.855	Amdt.	60
1986	Heat Release	FAR	25.853	Amdt.	61
1988	Heat Release and	FAR	25.853	Amdt.	72
	Smoke Density	FAR	25.853	Change	13

AIRBUS INDUSTRIE REGULATION

1979	AIRBUS Test Specification	ATS 1000.001
1994	ATS upgrade	ABD 0031

In 1979 Airbus Industrie established the ATS 1000.001 (Airbus Test Specification) representing an extended version of the FAA regulations with regard to smoke and toxicity requirements.
All Airbus interior materials had to comply with the more stringent ATS 1000.001 requirements.

It was the first time in the history of aircraft fire safety that smoke and toxicity requirements for interior materials had been applied.

In 1994 the ATS 1000.001 was superseded by the ABD 0031.

The ABD 0031 represents an increased FST standard, for e.g. a more severe, more stringent smoke emission limits for all non-metallic interior parts.

The ABD 0031 covers additionally all non-metallic structural component parts installed in the pressurized section of the fuselage.

GENERAL PERSPECTIVE ON AIRCRAFT SAFETY

Most of the established aircraft safety regulations are the result of individual accidents and their analyzed technical problems.

There was no real systematic approach for more aircraft safety.

In the meantime the aircraft industry and regulatory bodies started corresponding research on the following :

* To develop and evaluate quantitative risk assessment models of aviation safety including cost benefit analysis.
* To identify the consequences for aircraft safety of the effects of growing complexity of on-board systems, increased airframe and systems interaction and increased information processing integration.
* To develop and validate methodologies for the measurement of human effectiveness in the cockpit environment focussing on human confrontation to abnormal situations.
* To develop and validate new approaches to the understanding of safety related aspects of the human/machine interaction in future generation highly automated aircraft cockpits.
* To develop and experimentally validate new and improved analytical techniques which accurately describes the structural deformation of airframes, landing gears, seats and interiors during a crash impact or explosive loading.

Will lead to improved structural design capabilities resulting in enhanced passenger crash and fire protection.

PERSPECTIVE OF AIRCRAFT FIRE SAFETY

The perspective of aircraft fire safety can be classified in near term and future term fire safety research.

Near term activities are the following :

* Halon replacement
* Fuselage burnthrough resistance
* Cargo compartment protection (explosive hardening)
* Flight data recorder fire resistance
* On board water mist systems

The fuselage burnthrough resistance has been quantified as an important safety issue and that was the reason for the CAA to initiate a European programme which is composed of European airframe manufacturers for e.g. DASA, Aerospatiale, Fokker, Airbus Industrie and also European Airworthiness Authorities as, for e.g. CAA, JAA and European Test Institutes.

The objectives of the programme will be to identify the current weaknesses with regard to the penetration of the fuselage. Further research and development will lead to an understanding of the failure mechanisms involved in burnthrough. Design principles and methods will be established, a small scale test method suitable for industry will be developed and with the establishment of specifications and design guidance the optimum design and materials selected. The research shall lead to safer aircraft.

Accidents and tests have shown that the aluminum skin currently used on production aircraft fuselage can burnthrough within 60 seconds. Once burnthrough occurs conditions in the cabin rapidly become unsurvivable. There are no international regulations or internationally recognized techniques for the assessment of burnthrough resistance. There have been limited full scale fire tests conducted by the FAA. The CAA working within the JAA has instigated small and medium scale tests which have been conducted by members of this consortium.
The full scale tests are very costly and cannot be used alone for development purposes, currently there are no appropriate small scale tests. Small scale results cannot easily be compared to full scale results. Development of the medium scale test has bridged this gap in available development fire tests and proven that improvement to burnthrough resistance is possible.

The consortium will develop a test method that will identify new materials, and enable the introduction of new design principles and design methods which will make significant improvements to cabin safety.

In addition to these activities safety research with regard to on board water mist systems should continue considering new or advanced technologies taking into account weight and cost penalties.

Future fire safety research should be concentrated on the following :

* Fire modeling
* Improved fire/smoke detection and extinguishing systems
* Fuel safety
* Fire resistant materials

It appears that the research in fuel safety has to be increased since practically all post-crash aircraft fires are initiated by the ignition of jet fuel released from the damaged fuel system.

The objectives of the fuel safety research should be :

- to analyze the vulnerability of the fuel system in a fire scenario,
- to identify the weaknesses of fuel tanks in a post crash scenario,
- to develop safer fuel tanks and associated systems,
- to develop low ignitable fuel.

FIRE SAFETY RESEARCH OF MATERIALS

There is a wide range of safety research in cabin interior materials.

From the industrial point of view material research should be concentrated on the following goals :

- to reduce the ignitability,
- to develop materials with char capabilities,
- to reduce heat release,
- to reduce smoke and toxicity emission,
- to study fire endurance,
- to study and develop fire containment technologies.

As an important objective during the research into future materials ecological aspects have to be considered.

Materials which are suspected to be too dangerous with regard to health and environment will be more and more restrained.

Carcinogenic, mutagenic and teratogenic products as well as products harmful to the environment will be removed from production.

The objectives can be summarized as follows :

* Preservation of the natural basis of human life and nature
* Minimization of environmental strain
* Minimization of pollution during manufacturing, use and disposal
* Use of recyclable materials
* Minimization of health and safety risk by elimination of hazardous materials during production.

SUMMARY

Airbus Industrie is in agreement that aircraft safety has to be improved since the fatalities caused by accidents will increase due to the predicted increase in world air traffic and the move towards bigger aircraft.

Airbus Industrie will play an active role in this field and decided to lead an European programme with regard to Improved Fuselage Burnthrough Resistance.

Our current aircraft already represent a higher standard in safety since they comply with an extended version of the FAA regulations with regard to smoke and toxicity requirements for interior materials.

There is a need for a more systematic approach and research programs resulting in common regulatory requirements across national boundaries.

Airbus Industrie's concern is that shorter order-to-delivery time and a general reduction of production costs will decrease resources which are needed for the implementation of improved safety systems/ - designs or new materials.

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M.A.D. van der Heijde, May 1989, Tests for Aircraft Interior Materials in Fire Accident.
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Publication NMAB-477-2 Aircraft Interiors
Washington, D.C. 1995

It was my intention to attend this conference as part of the audience, just like yourselves.
But now I find myself up here, filling in for Theo Klems, representative of AIRBUS INDUSTRIE, who regrets very much that he is not able to be here today to present his paper "Industry perspective on what is needed in fire safety in person.

Mr. Klems is still in bed, I am sorry so say, where he is recovering from a successful operation.

However, he was able to complete his presentation for you before he was admitted to the hospital.

Mr. Klems is a valued colleague and as his topic touches on the area to which I am assigned at DAIMLER-BENZ AEROSPACE AIRBUS, it was decided last week, after discussion among those responsible, that I should present the paper prepared by Mr. Klems in the name of AIRBUS INDUSTRIE.

I ask you to understand that, should you have any question as to the content of the paper, I can only attempt to answer them as he would have done.

With respect to the topic "Industry perspective on what is needed in fire safety" my personal opinion is that the presentation you will hear shortly contains one industry perspective.

Other aircraft manufacturers might well choose different areas of emphasis, different priorities, different paths to the goal in general. But there is one goal that unities all of us, and that is : "zero accidents".

ABSTRACT

"The International Aircraft Materials Fire Test Working Group and What Industry Sees for Future Direction of This Group"

James M. Peterson
Boeing Commercial Airplane Group
Seattle, Washington, USA

The FAA International Aircraft Materials Fire Test Working Group was established by the FAA Technical Center in 1988 as an informal ad-hoc advisory group to help resolve persistent problems with flammability test procedures. Industry - aircraft manufacturers and their subcontractors, material suppliers, test laboratories, and others -- from many countries have supported this effort, and the Group has had considerable success in resolving these problems.

Subsequently, the role of the Group was expanded to address other issues related to fire safety being studied by the FAATC. This included internal FAATC initiatives, issues posed by the FAA/JAA/DOT Canada Cabin Safety Team, and items from recommendations to the FAA from the National Transportation Safety Board.

Industry believes that the International Aircraft Materials Fire Test Working Group provides a valuable forum for discussion of these issues, and that the Group should continue for this purpose. Meetings have been held three times a year -- once at the FAATC, once at a Group participant in the United States, and once at a Group participant outside the United States. The frequency of future meetings should be sufficient to appropriately support the work that needs to be done.

FAA INTERNATIONAL FIRE TEST WORKING GROUP

HISTORY AND THE INDUSTRY'S VIEW

James M. Peterson

Boeing Commercial Airplane Group

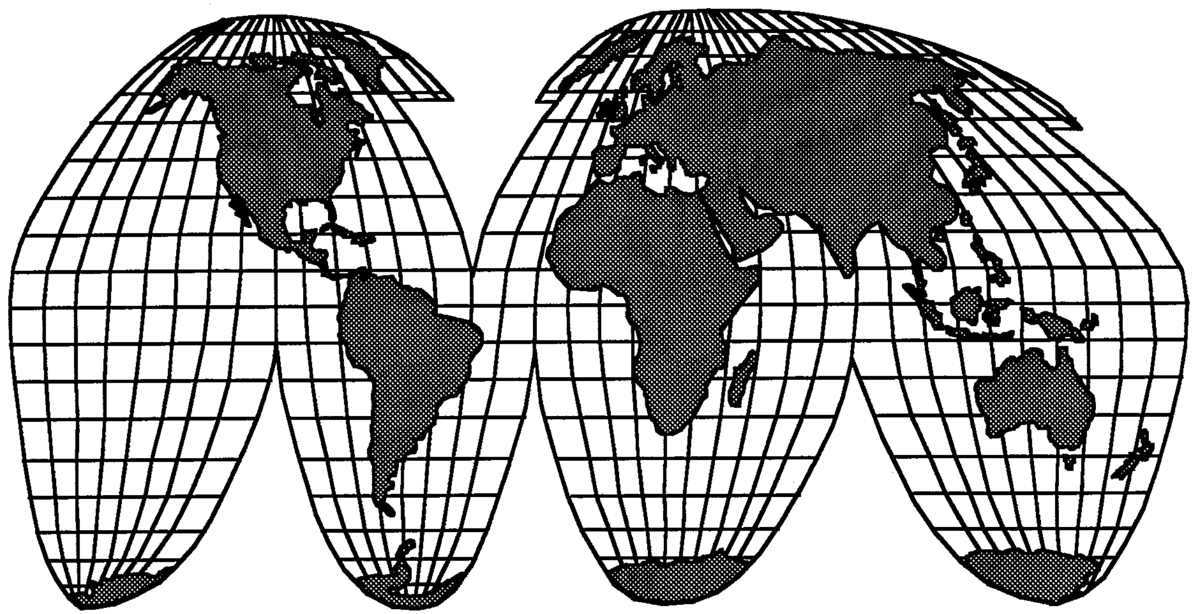
FAA INTERNATIONAL FIRE TEST WORKING GROUP

- What Is the Group?
- What Is Its Purpose?
- Who Participates?
- When and Where Does It Meet?
- What Is the Industry's View of It?

NEW FAA FLAMMABILITY REGULATIONS IN 1980s

- Escape Slide Radiant Heat Resistance
  - Special FAATC-Developed Device
- Seat Cushion Fire Blocking
  - First Oil Burner Variant
- Cargo Liner Burnthrough Resistance
  - Second Oil Burner Variant
- Cabin Liner Heat Release
  - OSU Calorimeter
- Cabin Liner Smoke Release
  - NBS Smoke Chamber

NEW FAA REGULATIONS ADOPTED WORLD-WIDE



NEW FLAMMABILITY TESTS ADOPTED

- Many Problems Encountered With Test Equipment and Procedures
  - Initially Very Large Variations in Test Results
  - Causes Not Well Understood or Identified
- FAATC Did Several Round Robins to Identify Causes of Variation
  - AIRBUS, Boeing, Douglas
  - Ohio State University
- A Systematic Discussion Forum Was Needed

FIRE TEST WORKING GROUP

- FAATC Established Group in 1988
  - Informal
  - Temporary
  - Knowledgeable Participants
- Purpose Was to Help Resolve Problems
  - Test Equipment
  - Test Procedures

GROUP PARTICIPANTS ARE INTERNATIONAL

- 50 - 75 Individuals Attend Meetings
- Aircraft Manufacturers
  - Airbus Consortium Partners
  - Boeing
  - Douglas
  - Fokker
- Material and Component Suppliers
- Regulatory Agencies
- Commercial Test Laboratories

CHARTER EXPANDED

- FAA Expanded Group Activities to Advise and Consult
  - All FAR Test Procedures, Especially Those Applicable to the Passenger Cabin Components
  - Update of FAA Fire Test Handbook (Requested by March 1993 by FAA Transport Directorate)
  - NTSB Requests
  - Cabin Safety Team (JAA, FAA, DOT Canada) Requests
  - Advanced Fire-Resistant Tests for New Materials (Aviation Safety Act of 1988)
- Standing Body
  - Future Meeting Times and Places TBD as Required

MEETINGS TO DATE TIMES AND PLACES

- FAA Technical Center, Summer
- North American Participant, Spring
  - Boeing, Seattle WA
  - Douglas, Long Beach CA
  - Schneller, Kent OH
- Non-North American Participant, Fall
  - DLR, Trauen
  - Deutsche Aerospace Airbus, Bremen
  - AVRO (British Aerospace), Manchester
  - Aerospatiale and CEAT, Toulouse
  - Schneller, Paris

NTSB AND CABIN SAFETY TEAM ISSUES

- **NTSB**
  - Development of Test Procedure and Acceptance Criteria for Blankets and Pillows
- **Cabin Safety Team**
  - Continued Compliance of In-Service Parts
  - Quality Control of Production Goods
  - Approval of Parts by Similarity
  - Approval of Repaired Parts

INDUSTRY VIEW

- Industry Supports the Group Activities
- Productive Forum for Discussing Fire Safety Concerns

Fuselage Burnthrough Program

Timothy R. Marker
Federal Aviation Administration Technical Center
Atlantic City International Airport, NJ 08405

Darren C. Dodd
Faverdale Technology Centre
Faverdale Industrial Estate, Darlington, England

Abstract

This paper describes the joint research project undertaken by the United States Federal Aviation Administration (FAA) and the United Kingdom Civil Aviation Authority (CAA) to evaluate and improve upon the fuselage burnthrough resistance of transport category aircraft to large fuel fire exposure. An earlier project served as the basis for this research, in which several surplus transport aircraft were exposed to large area fuel fires. During these tests, the fire entry points, likely fire paths to the cabin, and time frame involved for this to occur were investigated. The current project is an extension of this earlier work and involves the development of a full-scale test rig to further and more precisely investigate the problem areas, and then to evaluate design improvements aimed at prolonging burnthrough resistance to external fires. The development of a medium scale burnthrough test used for the screening of improved materials will also be discussed.

The project is divided into several phases: development of a full scale testing device, development of a medium scale testing device, and follow-on research leading to the potential development of specifications for materials/systems/components which would increase fuselage burnthrough resistance. The CAA has tasked Darchem Engineering to develop a medium scale test apparatus. To date, Darchem has completed its construction of the testing apparatus, and has logged hundreds of hours of testing at the Faverdale Technology Centre (FTC) in Darlington. The FAA had the responsibility of developing a full-scale burnthrough test rig, which was completed in 1995, at the FAA Technical Center in Atlantic City. Several tests have been completed in the full scale test rig at the time of this writing; the test results of both the medium and full-scale rigs will be discussed, along with future considerations.

Introduction

Postcrash fires are usually initiated by the spillage and subsequent ignition of jet fuel released by the fuel tanks damaged as a result of the crash. Because of the potential severe fuel fire hazards in accidents with major spillage, the FAA has supported research programs for anti-misting kerosene and fuel system crashworthiness that aim at minimizing or eliminating the fuel fire hazard. Although the size of the fuel fire is certainly important, other factors in the postcrash fire scenario may be of even greater importance. One such important factor is the integrity of the fuselage during an accident. Two possibilities exist: 1) a crash rupture or emergency exit opening exists, allowing direct impingement of flames on the cabin materials by an external fire, or 2) an intact fuselage. Based on a consideration of past accidents, experimental studies, and fuselage design, it is apparent that the fuselage rupture or opening represents the worst case condition and provides the most significant opportunity for fire to enter the cabin (Sarkos, 1988). It should be recognized that FAA cabin flammability standards for low heat release interior panels and seat cushion fire blocking layers were based on full-scale tests employing a fuel fire adjacent to a fuselage opening in an otherwise intact fuselage. By direct exposure of the interior materials to the intense thermal radiation emitted by the fuel fire, this type of scenario was representative of a severe but survivable fire condition against which to develop improved standards. However, in some crash accidents, the fuselage remained intact and fire penetration into the passenger cabin was the result of a burnthrough of the fuselage shell (Sarkos, 1990). Although the ignition of interior materials by an external fuel fire via fuselage burnthrough is expected to occur much later than when fuel fire impingement occurs directly through a fuselage opening, reported accident findings with fuselage burnthrough have produced fire fatalities but do not present a consistent behavior. At least ten transport accidents involving burnthrough

have occurred in the last 20 years, five in which the rapid fire penetration of the fuselage was a primary focus of the investigation, including Los Angeles 1972, Malaga 1982, Calgary 1984, Manchester 1985, and Anchorage 1987.

During an accident involving a Continental DC-10 at Los Angeles in 1978, a large fuel fire burned for 2 to 3 minutes before extinguishment by the Crash Fire Rescue personnel. Over this interval, the fuel fire did not penetrate and ignite the cabin furnishings, although there was some evidence of heat/flame damage at panel seams and along seat back cushions. It was clear from this accident that wide body transports (B-747, DC-10, and L-1011) could resist burnthrough for several minutes, as the fuselage walls of these aircraft are constructed of aluminum skin and heavy structural elements, along with thick thermal-acoustical insulation and honeycomb sidewall panels. Conversely, it was believed that narrow-body aircraft (B-727, B-737, MD-80) may allow flame penetration from burnthrough much more quickly because of the presence of aluminum sidewall panels, thinner thermal acoustical insulation, and in many cases a thinner aluminum skin (Sarkos, 1988). However, in the B-737 accident at Calgary in 1984, a fire resulted when the left engine failed and ignited the fuel released by the damaged nearby fuel tank. The fire was immediate and intensified as the aircraft was brought to rest almost 2 minutes later. Miraculously, 119 passengers and crewmembers were able to evacuate in an estimated 2-3 minutes, although portions of the cabin quickly filled with smoke when the exits were opened. The same could not be said of the B-737 accident in Manchester in 1985, which had a similar fire scenario as the Calgary accident, but in which 55 occupants perished from the effects of the fire. In this accident, it was believed that the external fire caused a very rapid burnthrough of the lower fuselage skin and quickly involved the cabin furnishings by gaining entry through the baseboard return air grills (reference AAIB Report). During an accident involving a B-727 at Anchorage in 1987, a large fuel fire developed on the ground adjacent to the aircraft when it was accidentally towed into a loading walkway, causing massive fuel spillage due to a punctured fuel tank. Although a large section of the fuselage skin melted away from the ensuing fire, it did not spread into the cabin, indicating that in some cases the fuselage could act as an effective fire barrier. One key difference between the Manchester accident and both the Calgary and Anchorage accidents was the presence of wind directing the fuel fire flames against the fuselage, which could have aided the rapid fire penetration.

Although fire can penetrate into the passenger cabin by a variety of mechanisms, including the windows, the sidewall (above floor), cheek area (below floor), cabin floor, and baseboard return air grills, there is no set pattern based on past accidents or experimental test data to indicate which area is the most vulnerable. Testing had been performed on the individual components (aluminum skin, windows, thermal-acoustical insulation, and sidewall panels) but had not been done on the complete fuselage shell system in which fire penetration paths and burnthrough times could be observed. For this reason, a test program was conducted to determine the mechanism and time framework for fire penetration into the cabin and ignition of the interior materials.

Initial Full-Scale Burnthrough Tests

To better understand and quantitate the fuselage burnthrough problem, the FAA conducted a series of full-scale tests by subjecting surplus aircraft (DC-8 and Convair 880) fuselages to 400 square foot fuel fires. The fuel fires were set adjacent to the intact fuselage sections which were instrumented with thermocouples, heat flux transducers, and cameras to determine penetration locations, firepaths, and important event times. During the tests, each aircraft was divided into three sections by installing exterior barriers and internal partitions to confine the fire within the section being tested. Thus, each aircraft was tested three times in the following sequence: aft, forward, center (Webster, 1990). In the DC-8 tests, the aircraft was resting on its belly, simulating a crash with collapsed landing gear; the landing gear was extended during the tests on the Convair-880, as shown in figure 1.

From the six tests, several major findings were concluded in terms of the likely entrance paths of the fire, and the time required to involve the cabin interior materials. The tests indicated that the aluminum skin provides protection from a fully developed pool fire for 30 to 60 seconds, and that the windows are

effective flame barriers until they shrink and fall out of place due to the radiant heat of the fire, allowing flame penetration. These findings were consistent with data obtained during the investigation of the above mentioned accidents. The tests also highlighted the importance of thermal-acoustical insulation at preventing fire penetration. According to the tests results, the insulation can provide a significant delay of the burnthrough process, provided it remains in place and is not physically dislodged from its position by the updrafts of the fire. Several other findings were recognized, including the ability of the flames to gain access to the cabin by first penetrating into the cheek area, and then progressing upward through the floor return air grills. Areas such as the empennage crawlthrough that are not acoustically insulated were also found to be more vulnerable to burnthrough than other parts of the insulated fuselage, again illustrating the important role of the insulation. Additionally, the cabin sidewall is not thermally stressed as long as the acoustical insulation is intact, and the cargo compartment may provide a buffer zone protecting the cabin from burnthrough from under the aircraft. In terms of fire severity, it was determined that the aircraft with its gear extended is more vulnerable to burnthrough from a ground level pool fire than an aircraft resting on its belly, mainly because of the increased temperatures sustained at the higher locations in the fire. The information obtained during this test project would be used as a basis in the development of the full-scale burnthrough test rig.

Development of a Full-Scale Burnthrough Test Rig

The next phase of the program involved the development of a test apparatus by which improvements could be evaluated, under realistic conditions. Prior to the construction and development of a testing apparatus, an effort was directed toward the use of actual fuselage sections for evaluating material and system improvements. Several 12 foot long sections of 707 complete with interior components were available to run successive tests on. The sections were well instrumented with thermocouples to determine burnthrough points and event times using a smaller fuel fire, measuring 8 feet by 10 feet, than in previous tests. The fuselage section was married to a full length 707 fuselage which was severed and separated, allowing insertion of the 707 test plug. Several other 12 foot sections of the fuselage would also be tested, in order to gain a sufficient level of confidence with this test arrangement. It became evident after the first test, however, that this arrangement required an excessive amount of man-hours to configure the test plugs to the point at which meaningful results could be obtained. The interior materials of the test plugs had to first be disassembled to allow thermocouple placement behind the skin and insulation. Along with the tedious job of reassembly, additional work involving the proper sealing of the fuselage at the mating seams, combined with differences in each plug due to interior and exterior structure variations (cargo compartments, lavatories, galleys, exit doors, wing boxes, etc.) caused this approach to be abandoned.

Realistically, a full-scale test "rig" should allow repetitive testing in which singular components could be systematically evaluated. To accommodate this, a 20 foot long steel test section was constructed, and inserted into the 707 fuselage (figure 2). This section may be mocked-up with aluminum skin and accompanying insulation, floor and sidewall panels, carpet, and cargo liner. The mocked-up section extends beyond the 10 foot long fire pan, eliminating the mating problems experienced in the 707 plug tests. Measurements of temperature, smoke, and fire gases (CO, CO_2, and O_2) are taken inside the test rig, along with video coverage at several locations to determine exact burnthrough locations and times (figure 3).

Prior to commencement of the mock-up tests, the apparatus was covered with Kaowool ceramic fiber blanket on the surface exposed to the fire; the Kaowool covered approximately half of the fuselage circumference, from center bottom to center top. The fuselage exterior surface was instrumented with thermocouples, calorimeters and radiometers in an effort to quantitate this size fire at different locations with respect to the fuselage (figures 4, and 5). During past test programs, fires of this size were ignited next to fuselages at the cabin floor level, adjacent to a Type A opening to simulate an open escape exit or fuselage rupture. It was determined from earlier tests, however, that from a burnthrough standpoint, a more severe condition would result when the fire pan is slightly lower than the fuselage, allowing the higher temperatures of the upper flame area of the fire to come in contact with the fuselage lower area. Two fire pan locations were tested, and the more severe of these two was established as the standard fire

pan placement for future material mock-up tests. These tests also provided information on the radiative and convective heat flux produced by this size fire. As shown in figure 6, the fuselage is subjected to a fire of between 14 and 16 Btu/Ft^2-sec maximum, as measured by a Thermoguage calorimeter which measures the combined radiative and convective heat flux. By comparison, the Thermoguage radiometers measured the radiative heat flux only, which reached approximately 12 Btu/Ft^2-sec. The gradual but steady drop off in the heat flux occurs as a result of the devices becoming sooted by the fire. The differences in the radiative heat flux are the result of two types of radiometer window materials (ZnSe and CaF_2), and two angles of incidence (136° wide angle, 90° standard).

In order to evaluate potential improvements in materials and systems for better resistance to fuel fire penetration, a baseline test arrangement was established using in-service materials (figure 7). An aluminum skin section measuring 8 feet high by 12 feet wide was installed on the side of the test section. The panel consisted of two sheets of 0.063 inch thick Alclad 2024 T3 aluminum, heli-arced together, each measuring 4 feet by 12 feet. The panel extended from the lower fuselage quadrant up to the window level, and was mounted to the test rig using steel rivets to reduce the potential for separation during testing. The remaining area of the fuselage was covered with 22 gauge sheet metal. The first several tests utilized custom-made insulation batting, consisting of Owens-Corning Aerocor fiberglass insulation encapsulated in Orcon brand heat shrinkable Mylar film, type AN-18R. The insulation and batting material was sized to fit in the spaces outlined by the vertical formers and the horizontal stringers of the test rig (figure 8). The insulation bats spanned the entire area of the aluminum skin (8' by 12'). In the cargo compartment, 0.013" "Conolite" BMS 8-2A fiberglass liner was installed in both the ceiling and sidewall areas facing the fire, and held in place by steel strips of channel screwed into the steel frame of the test rig. An M.C. Gill "Gillfab" 4017 honeycomb floor panel measuring 4 feet by 12 feet was installed in the cabin floor area, and covered with FAA approved aircraft quality wool/nylon carpet. The remaining cabin floor area consisted of corrugated sheet steel. Interior sidewall panels from an MD-80 aircraft were used in some of the tests; the panels utilize an aluminum substrate and do not meet the current FAR's regarding heat release rate. The outboard cabin floor area contained steel plate with 3 inch diameter holes to simulate the venting area between the floor and cheek area. Additionally, an aluminum mesh was installed below the sidewall panels to simulate the baseboard return air grills (figure 9).

Initial Baseline Test Results. During the first test, the fire burned through the aluminum skin within 30 seconds, and quickly displaced or penetrated the thermal-acoustical insulation bats, allowing flames to enter the cheek area within 40 seconds. The fire intensified, and ignited and burned through the cargo liner into the cargo compartment in approximately 60 seconds. Concurrently, the fire penetrated the cabin through the sidewall, as well as the floor return air grills. The actual point of first penetration into the cabin was difficult to decipher, since the fire propagated both the sidewall panels and floor return air grills within a short time of one another. The burnthrough location(s) were masked somewhat by the placement of sidewall panels over the insulation in the cabin. Early indications pointed to the lack of complete coverage by the thermal-acoustical insulation, which had been attached to the test rig by loosely packing it into the spaces between the stringers and formers, and duct taping all edges. Since a major objective is to determine the effectiveness of the thermal-acoustical insulation when it is not physically displaced, an effort was given to better secure the batting material. During the next test, in which the material configuration was identical to the first test, the insulation bats were oversized slightly and were clipped onto the steel formers using spring steel locking jaw clips. The excess insulation material was wrapped over the edges of the curved steel-channel formers, and clamped in place approximately every 16 inches to prevent the insulation material from becoming easily displaced.

Although the progress of the fire appeared to be slowed during the second test, data revealed that the temperature and gas buildup within the cabin occurred nearly identically to the first test. The thickness of the insulation became the focus for the next test, as there was some indication that the one inch thickness was unrealistic for this area of the fuselage. An inspection of several surplus fuselages revealed that the insulation was at least several inches thick in the sidewall area (the insulation actually becomes much thinner at the extreme lower section of the fuselage, as the acoustical requirements are not nearly as

stringent as in the cabin area). The thickness of insulation varies between aircraft, but was found to be at least several plies thick in the areas of the fuselage where the fire had penetrated during the first two tests. For this reason, a third test was run using three plys of thermal-acoustical insulation inside each insulation bat; the spring clamps were again used to hold the insulation in place. In order to better investigate the burnthrough point and time, the sidewall panels, cargo liner, and floor panels were not installed. The third test proved to be much more realistic in terms of burnthrough time when compared to the previous tests.

If this configuration also allows premature burnthrough, follow-on tests will be run using 5 ply and 7 ply insulation batting in order to obtain a baseline format which most closely represents the burnthrough process of an actual fuselage.

Future Testwork in Full-Scale Apparatus

From the results of the initial full-scale burnthrough tests, as well as the several tests completed in the burnthrough test rig, it is evident that the aluminum skin can be considered a given, providing at least 30 seconds of protection prior to melting and subsequently allowing flame impingement on the thermal-acoustical insulation. The material types and thicknesses of aluminum skin currently in use will likely be used in next generation aircraft to a large extent. This leaves the focus of the burnthrough problem between the time the fire melts through the skin, until the time it first enters the cabin, or more specifically on the thermal-acoustical insulation, which has already proven to be an effective fire barrier if not physically displaced. For this reason, both the method of attachment of the insulation and the flame resistance of the insulation itself will be studied. It may be possible to obtain several minutes additional protection from burnthrough by simply using attachment clips that won't melt and fail during exposure to external fires. Currently, there are several different methods of insulation bat attachment, most of which consist of thermoplastic washer type fasteners. In terms of flame resistance of the insulation batting, there are a variety of new technology materials ("Nextel", a ceramic fiber based material manufactured by 3M, and a carbon fiber based material manufactured by RK Carbon Fiber are examples) that can withstand elevated temperatures typical of a large fuel fire for extended periods of time. These materials will be evaluated in both the medium and full-scale test rigs to determine their feasibility and potential safety benefits. After the insulation is penetrated the least resistant path for flame entry into the cabin is via the air return grilles. This was evident in the earlier full-scale burnthrough tests (Webster, 1994). Intumescent paint may be a simple concept for delaying grille penetration.

Another area that will be studied closely is the burnthrough resistance of a composite skin fuselage. The use of composites in transport category aircraft has grown steadily due to the high strength and low weight associated with them. The fuselage skin of the High Speed Civil Transport (HSCT) could feasibly be constructed of a composite material, so an assessment of it's capabilities when exposed to large area fires must be addressed. From a burnthrough standpoint, a composite fuselage would likely offer greater burnthrough protection to a large external fire than aluminum. However, there is concern over the potential for toxic and combustible gases being released during flame exposure, which could present a severe hazard to the escaping occupants. It will be possible to evaluate this scenario using the full-scale test rig by replacing the aluminum skin with composite structure and measuring the resultant gases within the cabin.

Development of a Laboratory Scale Burnthrough Test Rig

During the early phase of the current joint research program, it was determined that the development of a small or medium scale burnthrough test facility could be beneficial in investigating the problem of burnthrough. A laboratory test facility which could replicate the full-scale conditions would allow for quick and inexpensive testing of improved materials and/or systems, and also serve as a screening device for evaluating new materials under consideration.

Definition of Heat Source. The search for information to define the heat source was concentrated on previous published test work, studies of postcrash fires, and the study of general pool fires. The literature survey carried out with the assistance of the CAA and the FAA produced a number of articles that related to the fire testing of aircraft and hydrocarbon pool fires. A review of data produced a wide range of values for the temperatures and heat fluxes developed by hydrocarbon pool fires, therefore the selection of a representative fire was difficult. When proposing the upper values of the representative heat source, the mean of the highest temperatures and heat fluxes from the previous experimental data were considered. The values are given below:

Temperature	1150°C
Heat Flux	160 kW/m^2
Gas velocity	2 m/s at 1150°C
Fire status	Fully developed
Profile of fire curve	Instantaneous rise to maximum level

The values agree with the values that FTC have previously experienced in fire scenarios relating to both the aircraft and general industry. Lower levels of heating were also considered, and were intended to represent a pool fire at a distance from the fuselage. However, in the previous studies there was no reference to a lower heating level, so it was decided that the maximum duration of heating required would be 10 to 15 minutes, at the end of which aluminum skin should have just melted. The lower level was therefore taken as the temperature at which the aluminum skin would typically melt.

Temperature	650°C
Heat flux	42 kW/m^2

It was expected that FAA test results would fall within the upper and lower levels as previously defined. Whilst defining the heat source an opportunity arose to conduct an indicative test on a commercial aluminum panel. The panel started to burn through after 80 seconds with a furnace aperture temperature of 950°C, demonstrating that the basic principle of using a furnace to simulate a pool fire scenario was a sound one.

Burnthrough Apparatus. After considering the published test data as well as previous testing experience, it was decided that the best method of producing a controlled and repeatable heat source was to design and build a dedicated gas fire test unit (figure 10). The basic system consists of a mild steel box, internal dimensions 2m by 2m by 1.5m, lined with ceramic fiber and powered by four 300 kW propane burners which fire tangentially to ensure that energy is transferred efficiently to the furnace wall. The floor of the furnace is brick-lined to provide the required heat energy, both convective and radiative, in the correct proportions. The air and propane gas supply are driven to the furnace by a fan and a pressurized gas supply, respectively. The roof of the furnace incorporates a manually operated sliding lid which when rolled back reveals a 1 meter square aperture on the top of the furnace. The sliding lid section has a plug type sealing action onto a 25 mm ceramic fiber gasket to ensure that no hot gases leak out during the furnace warm up period. The test sample is supported over the sliding lid in the roof section. When the furnace is heated up to temperature and soaked, the insulated lid is rolled back, allowing instantaneous thermal insult to the test sample for the duration of the test. The results show that this method of storing energy and then releasing it provides the rise in a repeatable form.

Commissioning. A primary objective of building the test apparatus was to produce a heat source that simulated a pool fire without the inherent fluctuations in temperature and heat flux of a real pool fire. A number of trials were devised to determine if the test apparatus could yield reproducible results while operated between the upper and lower test limits. Initial results demonstrated a significantly better level of reproducibility when compared to test results from real pool fires. The furnace temperatures were being held to within 2% of the desired value at 1150°C, which compared favorably with observed pool fire temperature fluctuations of up to 40%; the associated heat fluxes were reproduced with a level of repeatability of +/- 12% at the higher temperatures.

Early Burnthrough Trials. During the commissioning phase of the program some preliminary burnthrough trials were conducted to compare burnthrough times of the test apparatus with the FAA full scale test results. The comparison revealed a marked difference in burnthrough times, as the test apparatus samples required 2 to 3 times greater the amount of the full-scale duration to completely burn through. After re-checking and confirming the performance of the burnthrough facility, the values of temperature and heat flux being measured were actually in excess of those measured in the FAA pool fire. Subsequent trials conducted on a small number of aluminum samples yielded burnthrough times of the order of 180 seconds. As before, these results were not as expected, since previous FAA full scale tests produced burnthrough in 26 seconds on identical samples for similar values of temperature and heat flux.

At this stage it was suggested that this apparent discrepancy in burnthrough times could be due to soot being deposited on the sample in the early stages of the fire, leading to an increase in surface emissivity. This was in contrast to the gas powered facility where the clean burning nature of the fuel meant that no soot was produced. An increase in surface emissivity would allow a greater amount of radiant energy to be absorbed, resulting in shorter burnthrough times. Having established theoretically that soot deposition could be a major influence on the fuselage burnthrough time, more trials were carried out using 0.7mm aluminum panels, identical to those used during the commissioning phase. The bare aluminum test sample burnt through in 58 seconds at a height of 50mm above the aperture when subjected to a temperature of 1150°C and a heat flux of 200 kW/m^2. An identical panel was coated with a thin layer of soot from an acetylene torch and tested in the same position; burnthrough occurred in 8 seconds. At this stage the main program was postponed in order to more closely investigate the effect of soot deposition on aluminum panels in the early stages of a pool fire, and is relationship to burnthrough time.

Soot Deposition Trials. A simple sooting rig was constructed and a number of aluminum panels of different thicknesses were exposed to a small pool fire for different lengths of time. A clean aluminum panel has an emissivity of approximately 0.10. When exposed to the small pool fire for at least 30 seconds, the emissivity of the test sample increased to a value between 0.50 and 0.80. The separate sooting trials showed that surface emissivity is dependent on the time that a surface is exposed to an adjacent enveloping pool of fire. The pool fire used in the sooting investigation was smaller than a typical postcrash fuel fire to enable a range of emissivities to be obtained so that a relationship to burnthrough time could be established. Although the surface emissivity of the aluminum increased to a value between 0.50 and 0.80 after 30 seconds exposure, this may occur after only a few seconds during a large scale pool fire.

A series of burnthrough trials were conducted using the sooted aluminum panels to develop a relationship between emissivity and burnthrough time. At low surface emissivities, burnthrough time decreases rapidly as surface emissivity increases, but once the surface emissivity approaches 0.60, any further increase subsequently produces a very small decrease in burnthrough time. For this reason, burnthrough times are very similar for surface emissivities of 0.60 to 0.90. A plot of surface emissivity vs. burnthrough time is shown in figure 11.

Cold Sooting Facility. It was concluded that for the test apparatus to accurately represent a postcrash pool fire, the emissivity of the sample must be controlled and therefore, all samples need to be pre-conditioned to an appropriate emissivity value before testing. It was necessary to develop a method for sooting samples without the risk of heat damage occurring, so that a wide range of materials could be tested. A technique was developed which enables the soot to be deposited without the need for exposure to intense fire conditions, hence the term "cold sooting" (figure 12).

A frame is laid across the rig's modular racking system into which the sample is placed. The sample frame has a runner at each corner that enables the frame to traverse smoothly along the racking system. A wire and pulley arrangement allows the sample frame to be moved along the length of the rig from outside the enclosure. A tray is centrally positioned underneath the rig and contains a strip of ceramic fiber

material soaked in kerosene which acts as a wick. A cover is positioned over the tray so that only a narrow strip of material protrudes, which is then made to burn.

Investigation of Burnthrough Parameters. The next phase of the program sought to identify the parameters most likely to have an effect on burnthrough time. The parameters chosen were surface emissivity, material thickness, external paint, structural features and the presence of insulation. Once these features were identified, a series of burnthrough trials were conducted in an attempt to assess the affect each had on burnthrough time. Several conclusions emerged from this phase of work.

The importance of surface emissivity has already been covered. As expected, burnthrough time increases as material thickness increases. A 0.9mm aluminum panel with a surface emissivity of 0.64 burnt through in 24 seconds. A 2.0mm aluminum panel with an identical surface emissivity burnt through in 43 seconds. The presence of paint covering on an aluminum panel does not necessarily affect burnthrough time. The change of surface emissivity, if any, resulting from the application of the paint is the important consideration. Aluminum panels containing typical structural features burnt through between 5 and 10 seconds slower than similar panels with no additional features. The difference can be attributed to the increase in structural integrity achieved by the presence of a double thickness of aluminum in the region of the feature. The presence of the insulation material seems to have little effect on burnthrough time for the aluminum panel.

Burnthrough of Fuselage Systems. This phase of the program sought to build on the burnthrough tests carried out in previous phases. The work was comprised of the following: a comparison of insulation materials, the burnthrough of existing fuselage systems, and an investigation into the performance of new materials. In addition to the determination of burnthrough times, the objective of this phase was to investigate the impact smoke emission and toxic gas release may have on occupant survivability.

Toxic Gas and Smoke Measurement. For the measurement of toxic gas and smoke emissions, several modifications were made to the burnthrough apparatus including a furnace hood extension used to contain any gas or smoke release, and a small collection hood positioned centrally above the furnace aperture which is connected by a length of stainless steel pipe to a cylindrical stainless vessel. Both the lengths of pipe and the vessel are insulated and maintained at a temperature above 100°C by means of resistive heating element. A small pump draws gas into the collection hood along the pipe and into the collection vessel, from which gas samples are drawn off for measurement. Measurement of specific toxic gases is done using a gas analyzer which combines Fourier transform infrared spectroscopy (FTIR) with photo-acoustic spectroscopy (PAS). It can be used to determine the composition of gas samples and can also be used to make repeated concentration measurements for up to 7 gases simultaneously. Almost all gases that absorb infrared light can be measured. The gases chosen to be monitored were carbon monoxide, carbon dioxide, hydrogen chloride, hydrogen bromide, and hydrogen fluoride. In addition, the concentration of oxygen is measured continuously throughout the test using a combustion efficiency analyzer for on the spot gas analysis. It consists of an instrument and an analyzer unit which evaluates and calculates the measured data. A pump draws the gas to be examined via a probe, which is cleaned by means of a condensate separator and a course filter and is then supplied to the incorporated oxygen measuring cell.

To quantify the smoke release from a particular sample, the following arrangement exists. On one side of the central flue a light source is positioned and on the opposite side of the flue there is a photo cell. The amount of light detected by the cell is represented as a voltage which is directly proportional to the light intensity. The amount of smoke released is then measured as the percentage reduction in light transmission.

Comparison of Insulation Materials. During this phase of the program, an attempt was made to compare different types of in-service encapsulated insulation. The materials selected were glass fiber, carbonaceous fiber, and polyimide foam. All insulation systems tested displayed both superior and inferior qualities in a variety of comparisons. It was observed that the presence of insulation can delay

flame penetration following skin melting from between 20 seconds to 8 minutes, depending on the type. In order to assess the suitability of the insulation materials tested, a clearer indication of the criteria for failure needed to be established, whether it be burnthrough resistance, loss of structural strength, toxic gas and smoke emission or more likely a combination of all these.

Burnthrough of Existing Fuselage Systems. The majority of testwork to date had involved testing flat aluminum panels, whereas in this phase burnthrough tests were conducted on actual fuselage sections. In addition to the outer shell, other fuselage components were tested, including insulation, interior sidewall panels, corrosion inhibitors, and passenger windows. For most of the burnthrough tests, the aluminum skin melted after 35-45 seconds. The presence of fiberglass insulation appeared to delay burnthrough to the inner face by an additional 60 seconds. During tests involving passenger windows, the window tended to be the weakest part of the structure, and failed to remain in place after less than a minute. The window seal burnt, the aluminum around the window distorted, and the window dropped out.

The use of corrosion inhibitors emerge as an area of concern. Corrosion inhibiting compounds commonly known as "goop" are hydrocarbon based water displacing compounds and tend to be highly flammable. Airframe manufacturers and maintenance facilities apply verying quantities of these anti-corrosion compounds to the interior of the fuselage. The testwork demonstrated the tendency of these compounds to cause the cold face of the test sample to flash with flames within 15 to 20 seconds of exposure to representative conditions. Such an effect could in turn cause the insulation bats or any dust/debris to ignite and propagate a fire before the exterior fire has actually penetrated the fuselage skin. The interior panels tested performed poorly, giving off dense black smoke immediately following exposure of the back face to the radiant heat, which was typically 100 seconds.

As part of an earlier phase of the program, tests were conducted on a cabin floor material. The composite panel was a structural grade laminate consisting of Nomex aramid fiber/phenolic resin core faced on both sides, with unidirectional cross-plied glass fiber skins. When subjected to conditions representative of a post crash fuel fire, huge plumes of dense black smoke were given off within seconds, for the duration of the test. In a real crash situation, it may be unlikely that the cabin floor receives the full effect of the fuel fire, but the performance of the floor material suggests that an investigation into the fire properties of these materials is necessary.

Investigation of New Materials. Aluminum alloy is by far the most common material currently used in aircraft structures, and will likely remain for a number of years. However, advanced alloys, metal composites, and reinforced plastics may make progressively larger inroads. This section sought to investigate the behavior of materials currently being produced or considered as replacements for existing aluminum alloys. Two types of materials were tested: an 8000 series aluminum alloy containing approximately 2.5% lithium (in addition to the usual constituents), and various fiber-metal laminates consisting of alternate layers of thin, high strength aluminum alloy sheets with fiber-impregnated adhesive.

Initial results indicated the aluminum/lithium alloy provided slightly greater burnthrough resistance than existing aluminum alloys, by approximately 20%. Both fiber-metal laminate configurations appeared effective in delaying the penetration of fire, but within the first minute of the test, substantial amounts of smoke were produced, making it impossible to determine how much of the structural integrity of the panel remained. The burnthrough resistance of this system was clear however, as it resisted penetration for 3-4 times longer than conventional aluminum alloys.

Overall Conclusions. A medium-scale burnthrough apparatus and test method have been developed which can replicate the conditions of a full-scale postcrash fuel fire, providing an effective screening tool for materials under consideration and enabling new protection systems to be developed. It is anticipated that the apparatus will compliment research conducted in the FAA Full-Scale test rig in order to bring about improvements in the burnthrough resistance of fuselages.

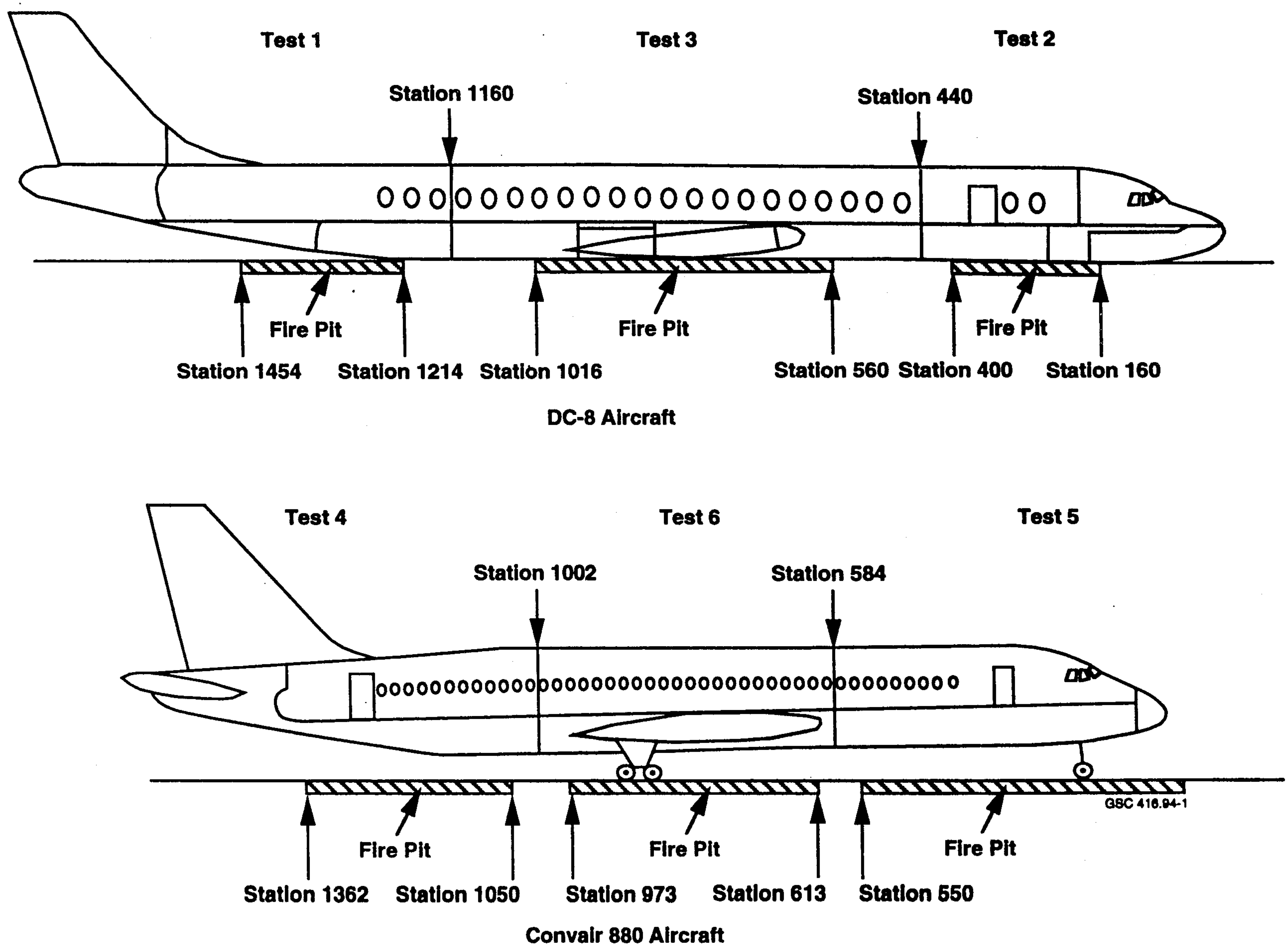

Test 1
Test 3
Test 2
Station 1160
Station 440
Fire Pit
Fire Pit
Fire Pit
Station 1454
Station 1214
Station 1016
Station 560
Station 400
Station 160
DC-8 Aircraft
Test 4
Test 6
Test 5
Station 1002
Station 584
GSC 416.94-1
Fire Pit
Fire Pit
Fire Pit
Station 1362
Station 1050
Station 973
Station 613
Station 550
Convair 880 Aircraft

figure 1.

FUSELAGE BURNTHROUGH TEST RIG

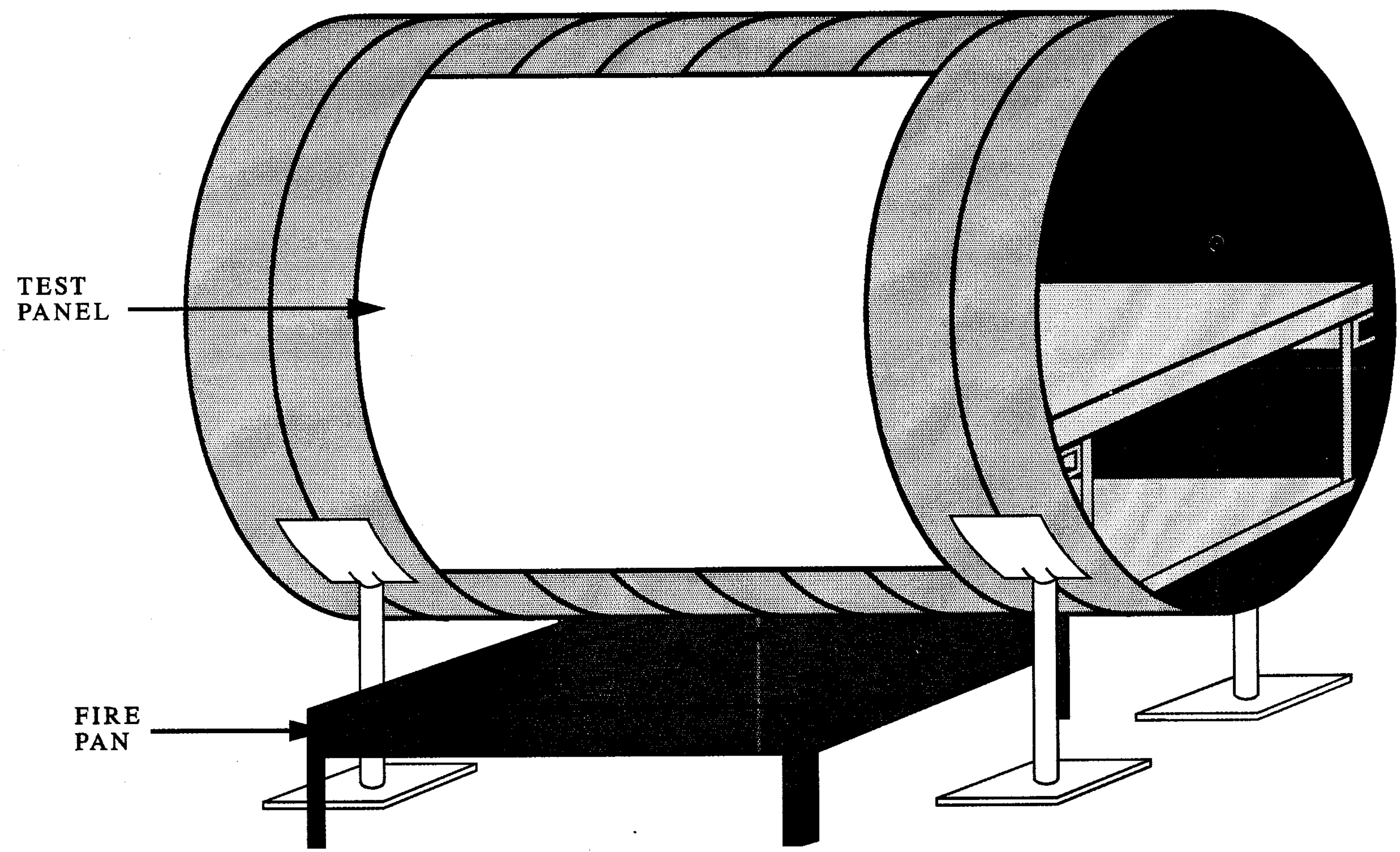


figure 2

INSTRUMENTATION LOCATION

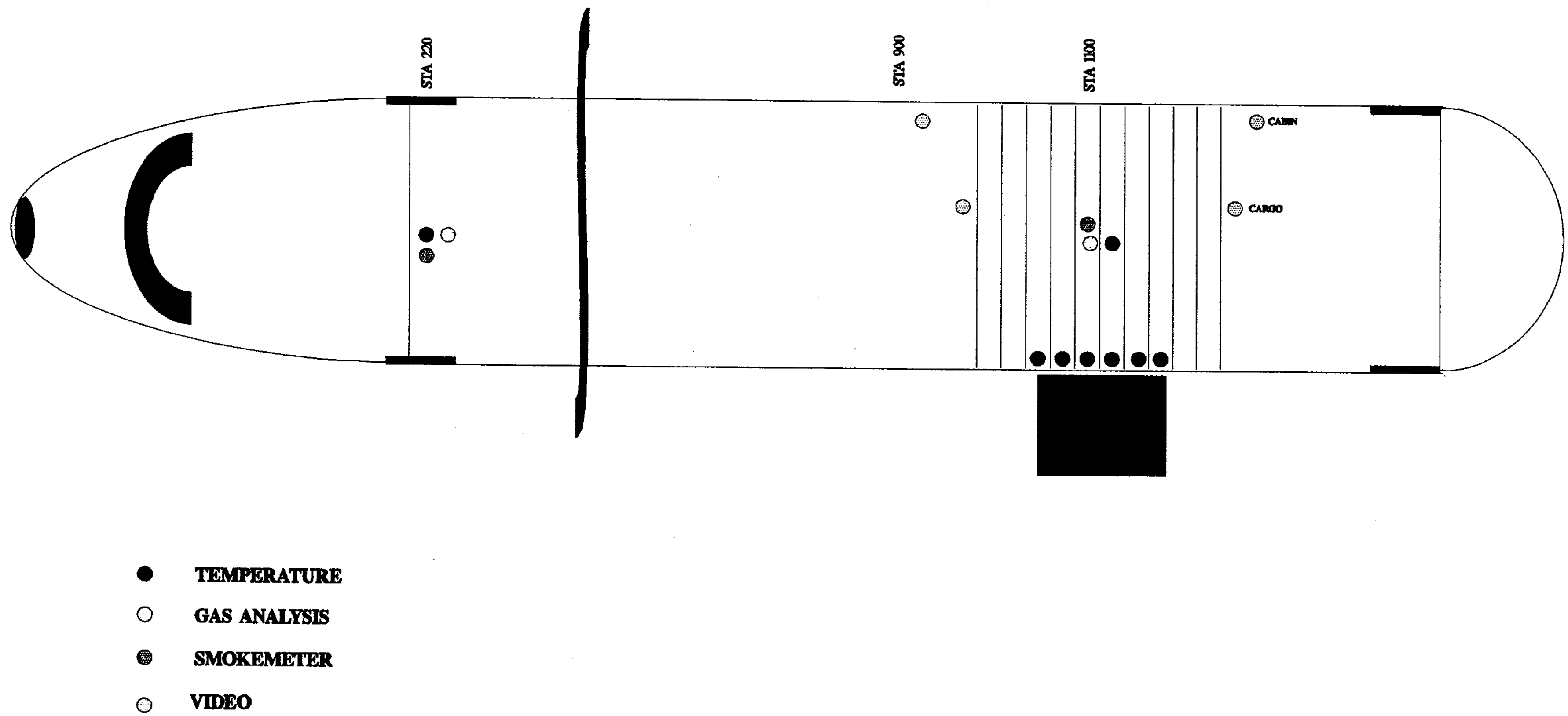
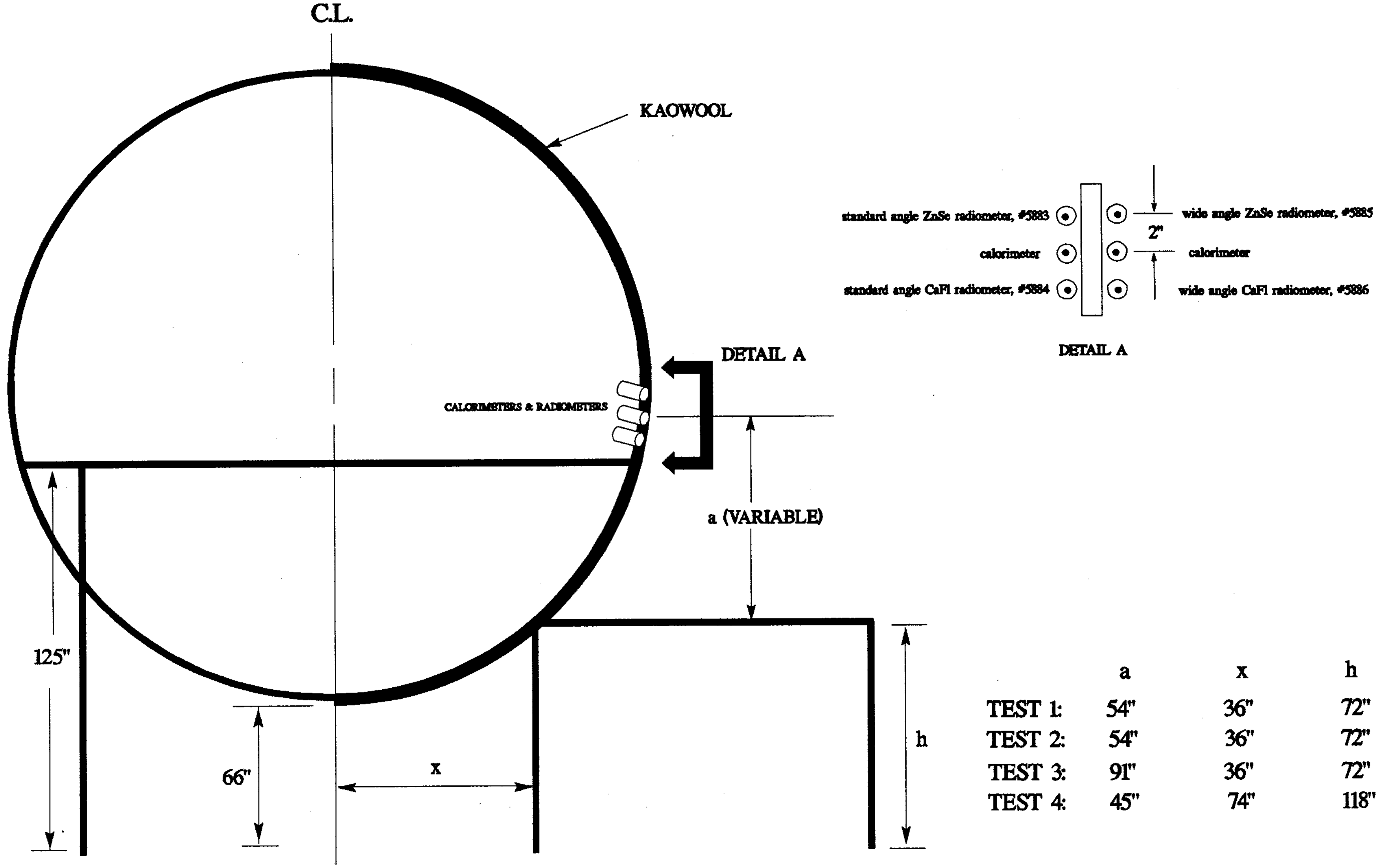


figure 3

CALORIMETER & RADIOMETER LOCATION



	a	x	h
TEST 1:	54"	36"	72"
TEST 2:	54"	36"	72"
TEST 3:	91"	36"	72"
TEST 4:	45"	74"	118"

figure 4

THERMOCOUPLE LOCATION

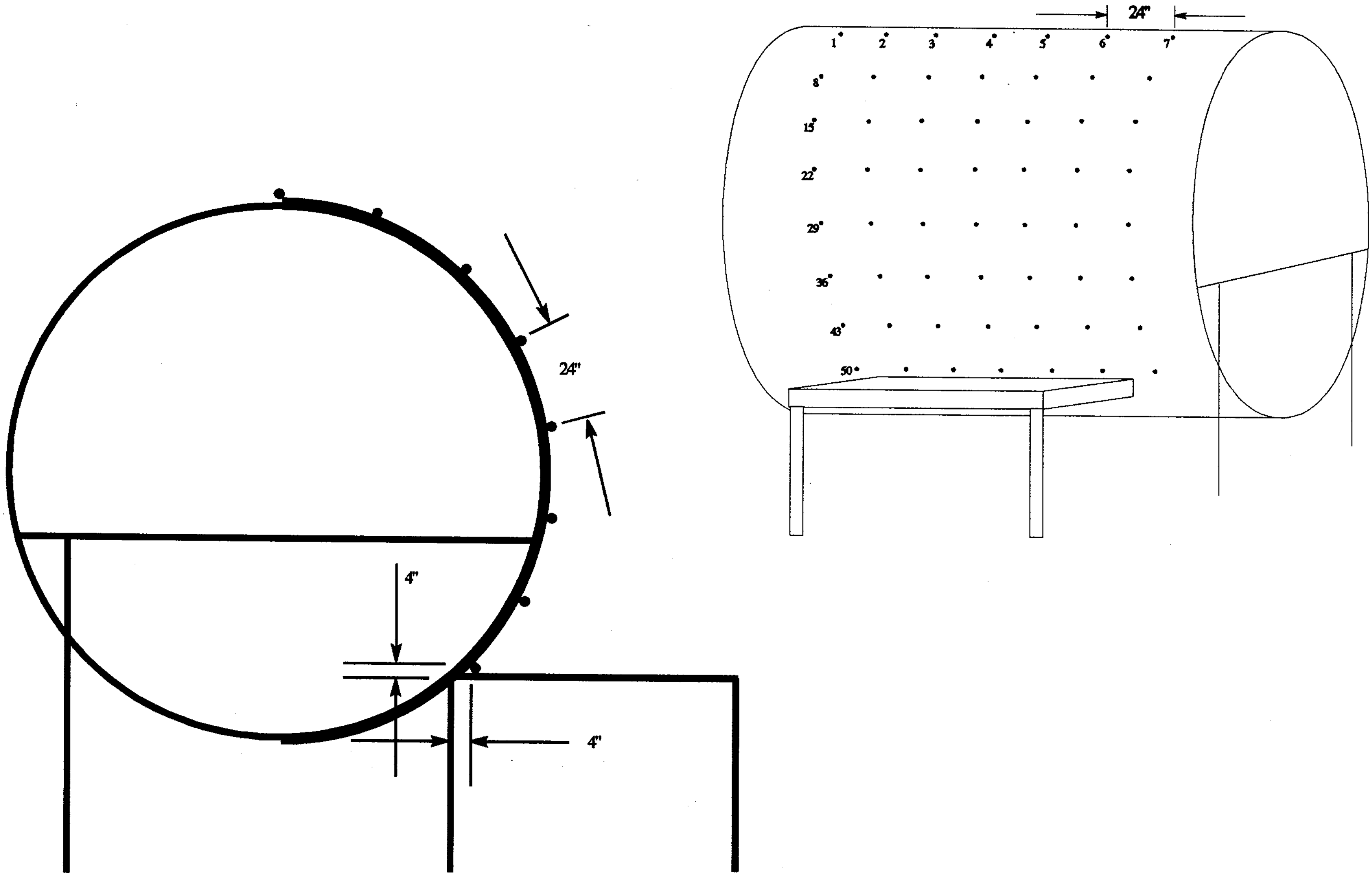


figure 5

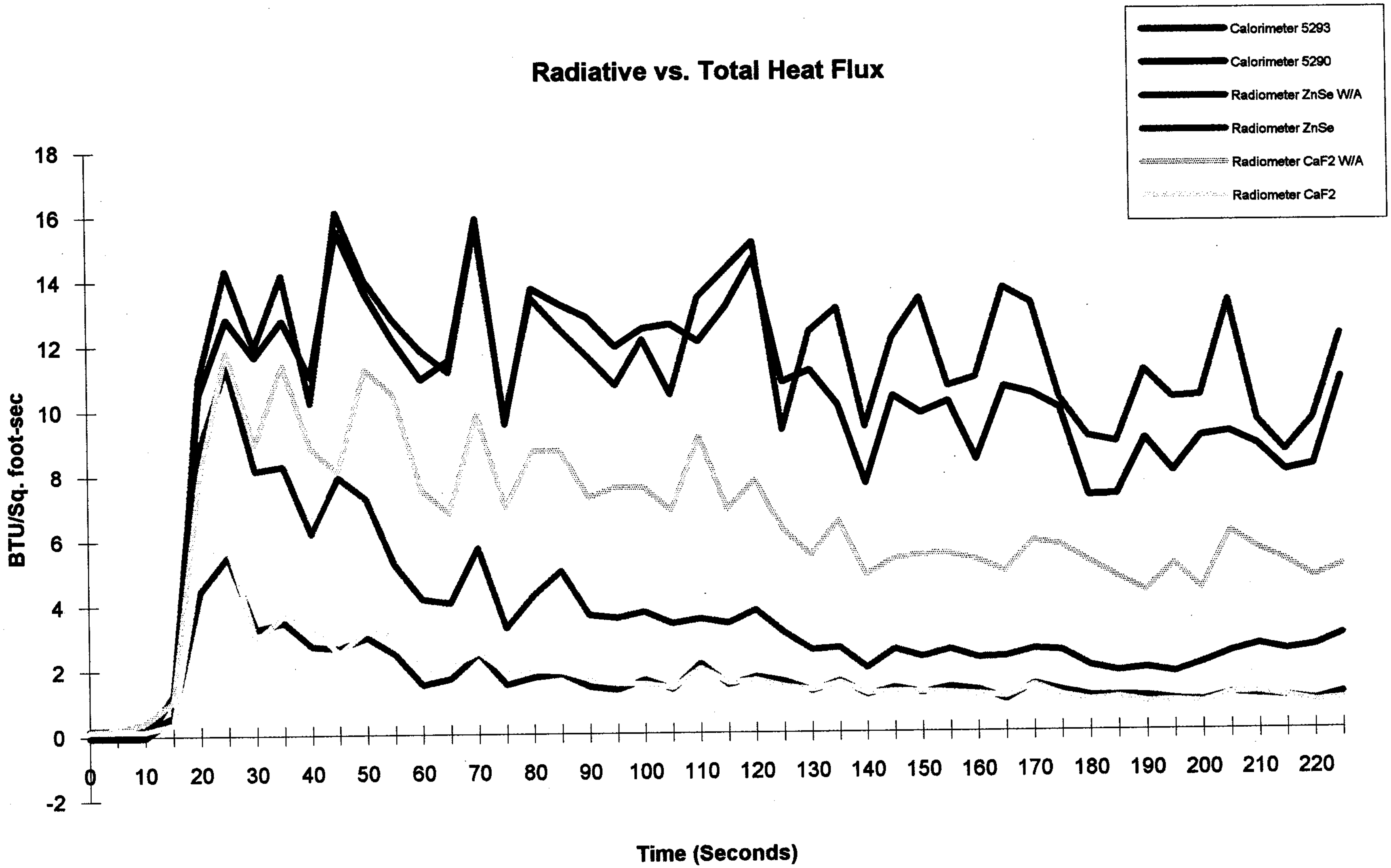

Radiative vs. Total Heat Flux
Calorimeter 5293
Calorimeter 5290
Radiometer ZnSe W/A
Radiometer ZnSe
Radiometer CaF2 W/A
Radiometer CaF2
BTU/Sq. foot-sec
18
16
14
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
Time (Seconds)

figure 6

TEST RIG CROSS SECTION
MATERIAL USAGE AND LOCATION

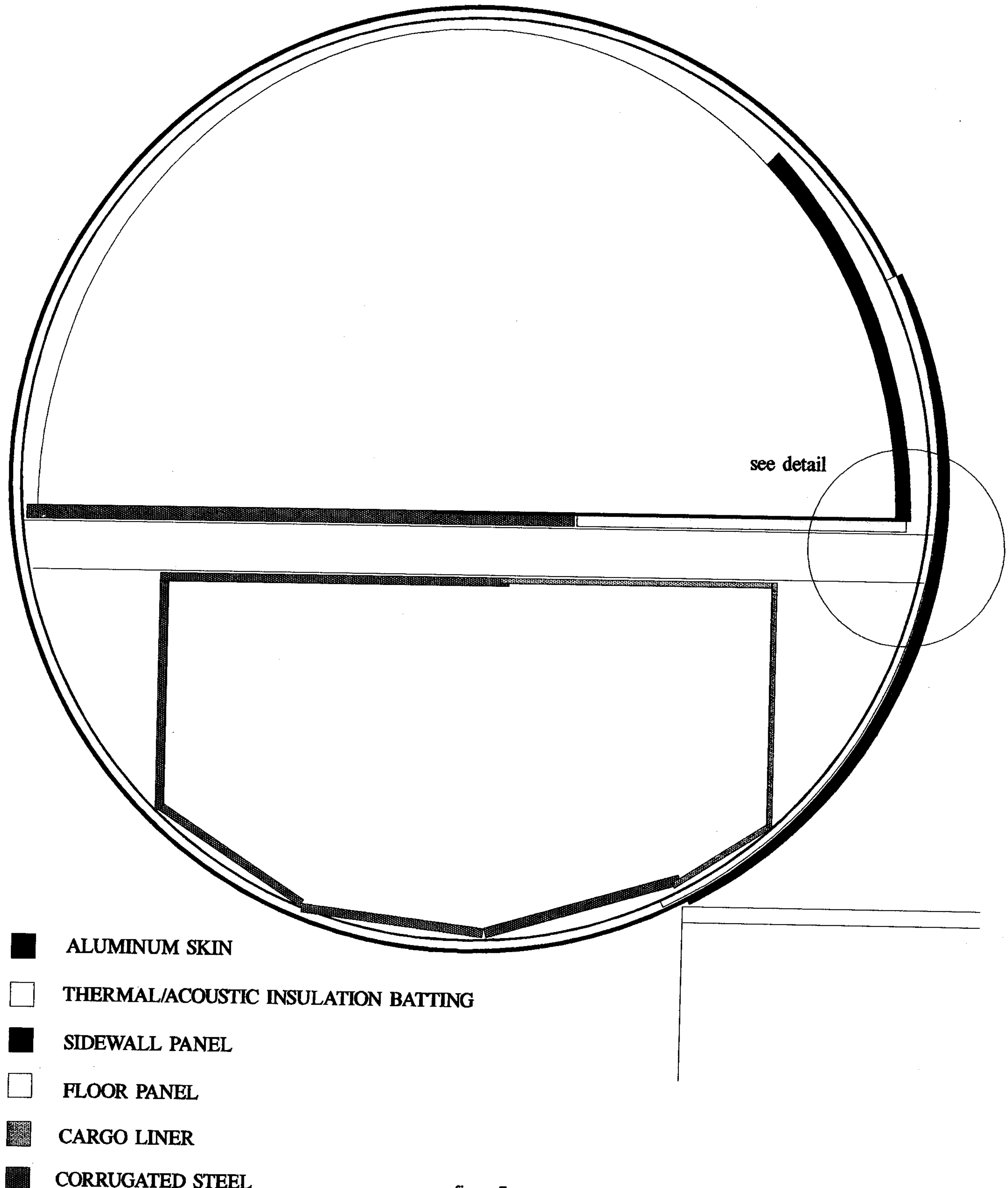


figure 7

INSULATION BATS

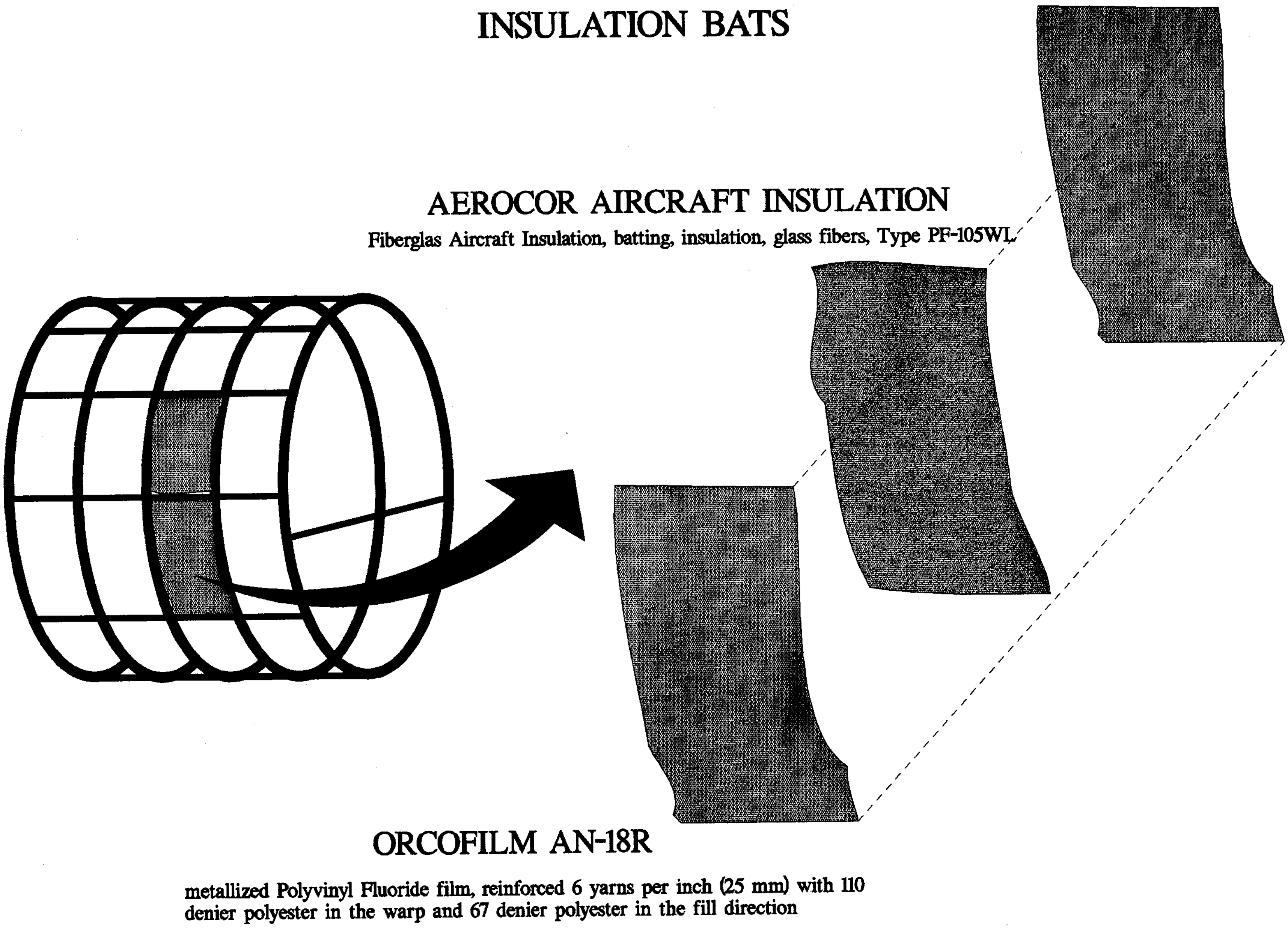


figure 8

CROSS SECTION DETAIL

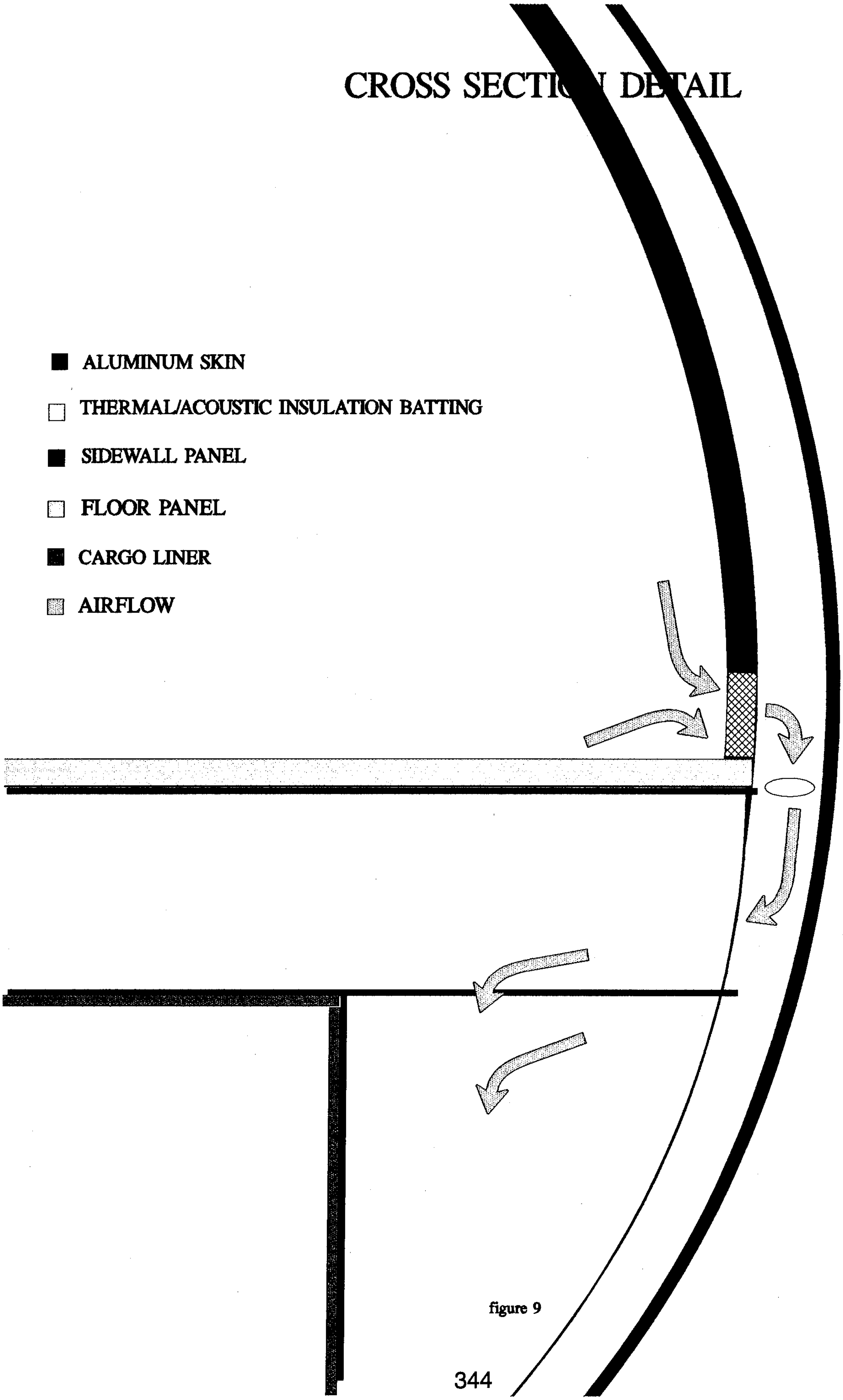


figure 9

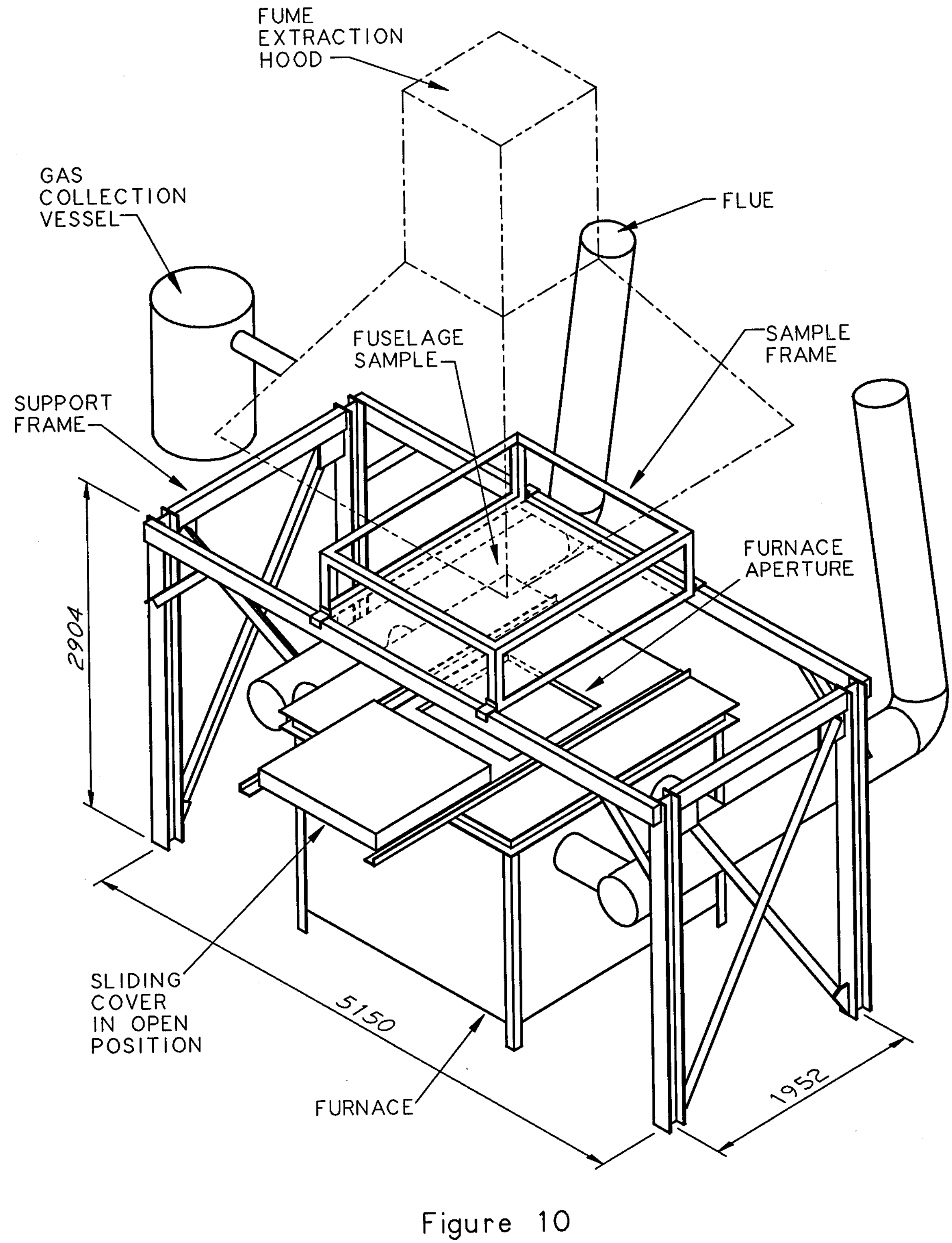


Figure 10
FUSELAGE BURNTHROUGH TEST FACILITY

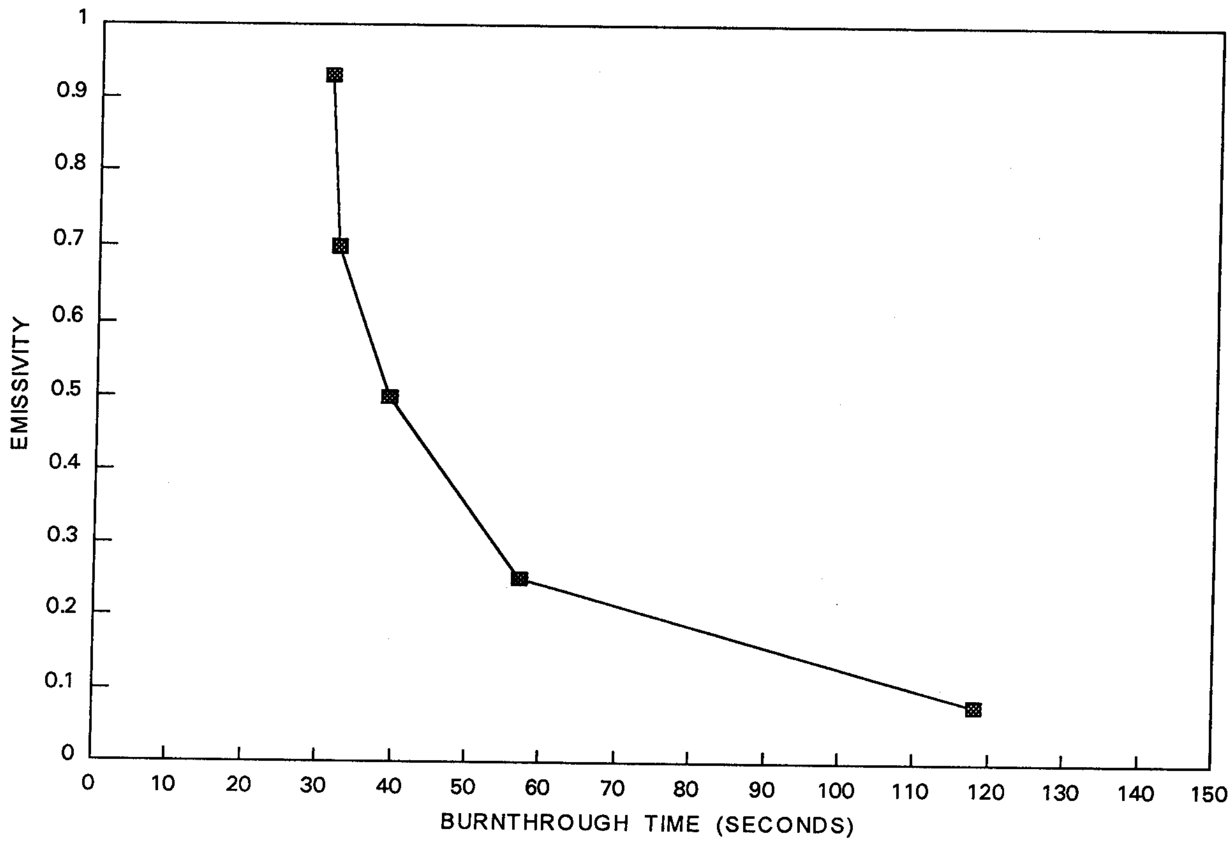


Figure 11
Surface Emissivity Against Burnthrough Time

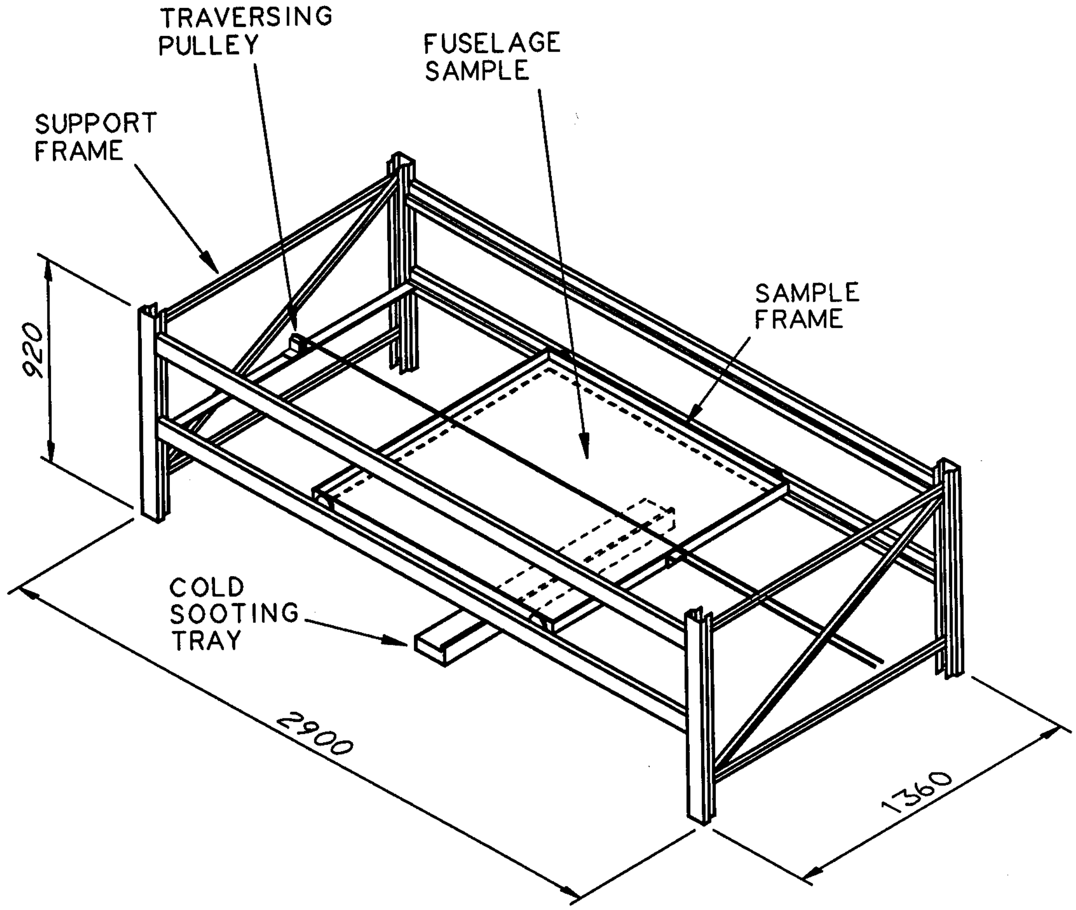


Figure 12
COLD SOOTING RIG

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Summary

This paper reviews past experience which led to the requirement to carry Halon 1211 extinguishers in the cabin of public transport aircraft and how this requirement fits with the overall fire prevention philosophy applied to the design of aircraft. Recent incidents and research are presented which highlight the capabilities of Halon 1211 as an extinguishing agent. The efforts of the International Halon Replacement Working Group and the development of a test method contracted by the UK Civil Aviation Authority is presented. These efforts are targeted towards defining certification standards for new environmentally friendly fire extinguishing agents that can replace Halon 1211. The standards are designed to ensure that no loss of safety will result.

Nick J Povey
Research Project Manager
Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick Airport
West Sussex
RH6 0YR

THE ROLE OF THE HALON 1211 HAND HELD FIRE EXTINGUISHER IN THE CABIN

The five following questions are to be addressed:

1. Why carry handheld extinguishers on aircraft?
2. Why use Halon 1211 as an extinguishing agent?
3. Why change from halon?
4. How do we ensure no loss in safety?
5. What further efforts can be made to improve fire safety in the cabin?

Why carry handheld extinguishers on aircraft?

The design philosophy adopted by all manufacturers and reinforced by the airworthiness requirements is to minimise the likelihood of a fire occurring. This aim is achieved by a number of different means; only materials which are heat and fire resistant or fireproof are used in areas considered to be vulnerable, the location of potential ignition sources is carefully controlled. Flammable fluids are similarly kept well away from heat and electricity. In addition to these physical measures there are also procedures adopted by the operators of the aircraft, these range from ensuring the integrity of systems during routine maintenance, the cleaning of dust and rubbish from the cabin and air return grilles, to the purposeful checking of lavatories regularly during flight for any signs of smoke or fire. Further restrictions are placed on passengers to ensure that they do not bring hazardous materials onto the aircraft and to control smoking to only those occasions when they are seated.

However as we all know things can and do go wrong and the unexpected happens, it is on these occasions that the adaptable and resourceful human being can be invaluable, provided they have a capable fire extinguisher available to them. This is the reason that handheld extinguishers are carried on aircraft.

Why use Halon 1211 as an extinguishing agent?
To effectively answer this question it is necessary to consider the alternative agents. Across all applications water is the most commonly used fire fighting agent, it also has a role in aviation and is used in aircraft cabins. It cannot be used on electrical or fuel fires but is very good in extinguishing class A fires such as trash container fires consisting of burning paper. It is excellent at cooling materials and preventing re-ignition.

Carbon Dioxide (CO_2) extinguishers have been used on aircraft in the past but have very limited class A fire fighting capability in relationship to the size and weight of the required extinguisher. They cannot be used safely on electrical equipment because of the risk of thermal shock from the dry ice expelled by the extinguisher.

Chemical Powder extinguishers suffer from many disadvantages. The powder when discharged forms a cloud restricting visibility, thus they cannot be used in the cockpit of an aircraft, in addition the powder when it settles would cover instrument faces making the instruments unreadable. The powder can cause electrical failure of switches (usually by insulation of the contacts) and finally the residue is corrosive to an aircraft structure and components, and therefore requires very careful cleanup after a discharge.

Halon 1211 has quite good class A fire fighting ability, is not very critical with respect to operator technique and can used on fuel fires (class B) and fires involving electrical energization (class C). The agent is relatively efficient which enables the extinguisher to be physically quite small. The use of water to dampen a fire after extinguishment with Halon 1211 is recommended. As noted by Krasner[1] there are many sources of water available in an aircraft cabin, including coffee and soft drinks.

In August 1980 a new FAA Advisory Circular 20-42A was issued entitled "Hand Fire Extinguishers for Use in Aircraft" this indicated the acceptability of an Underwriters Laboratory (UL) toxicity rating of 5 or higher and for the first time allowed for the use of Halon 1211. At approximately the same time a series of hijackings took place, all using volatile liquid as the threat. The FAA Technical Centre in Atlantic City conducted a series of tests and in November 1980 a general notice was issued which encouraged operators to carry at least two Halon 1211 extinguishers. The tests conducted at this time demonstrated that Halon 1211 was the best available agent[2] and that potential toxic breakdown products were not an additional hazard[3].

Halon 1211's full chemical name is Bromochlorodifluoromethane or BCF for short. It is a liquid when stored at pressure, which is typically 130 psi for an extinguisher, but has a boiling point of -4 degrees centigrade. It is thus a gas at room temperature. In practice the agent leaves the extinguisher primarily as a clear liquid which enables it to be directed towards the fire, it then rapidly evaporates to become a gas. It acts chemically to prevent combustion and requires greater than only 3.5% concentration to achieve this. It is thus easy to use and also forgiving of poor fire fighting technique.

In ground based applications Halon 1211 is acceptable for use as a hand held extinguishant but not for fixed systems in occupied spaces due to it's toxicity. However the tests previously

mentioned[3] demonstrated that a more toxic agent that puts the fire out very quickly with the use of only a small quantity of agent could be safer for passengers in the cabin than a less toxic but less effective agent. This is because the hazard that the passenger has to endure is the combination of the toxic threat of the agent together with the toxic threat of the combustion products from the fire, and it is the fire which rapidly becomes the most extreme hazard.

Toxic threat of the agent + Toxic threat of fire products = Gross toxic threat to passenger.

Past experience of fires in aircraft cabins confirms that it is a rare for a fire to occur. The statistics also confirm that the vast majority of incidents are readily resolved by the flight attendants. Table 1 records the percentage of reports of smoke or fire by location within the cabin. Table 2 records the percentage of actual discharge of extinguishers by location within the cabin. By comparison of the number of incidents recorded for each of the two tables it can be surmised that many incidents, particularly those related to the galley, are resolved without the need for an extinguisher.

Location in Cabin	*Percentage*
Galley	67%
Passenger Cabin	16%
Lavatory	10%
Flight Deck	5%
Overhead Area	1%
Cargo	1%

Table 1 Reports of Fire or Smoke

Location in Cabin	*Percentage*
Passenger Cabin	32%
Galley	27%
Lavatory	27%
Flight Deck	9%
Other	6%

Table 2 Reports of Extinguisher Use

Ignition Source	*Percentage*
Electrical	38%
Cigarette	28%
Not recorded	15%
Oven	7%
Other	11%

Table 3 Ignition Source

From reading the description of the events it is clear that in only a very small percentage of the incidents is the location of the fire not immediately evident. The majority of the data above was recorded prior to the more widespread restrictions on smoking. There is now some evidence developing which suggests that incidents in the passenger cabin are diminishing whilst reports of illicit smoking in lavatories is increasing.

Two incidents recorded in the United Kingdom demonstrate the positive manner in which the crews dealt with the incident, and that they obviously felt that they had the situation under control:

> On a flight from Newcastle to Tenerife. “Fire in gashbag”, “Extinguished with water/glycol and coffee. The coffee appears to have been the more successful extinguishant”.
>
> On a flight from Houston to London. “An intoxicated passenger set the seat alight with a cigarette”, “The fire extinguisher was used on the passenger, the fire went out”.

In addition there are incidents recorded which demonstrate the need to cater for the unexpected:

> "Passenger dropped cigarette into bag of passenger seated behind. Bag immediately caught fire and set the surrounding carpet alight".
>
> "Passenger stowed a bag containing a chainsaw in overhead locker, gasoline seen dripping from locker"

The Cincinnati DC9 accident of 2 June 1983 clearly demonstrates that the most dangerous fire is one that is hidden from the cabin. Figure 1 illustrates what is meant by "hidden" areas. In this accident an in-flight fire in a lavatory developed behind the trim. One CO_2 extinguisher was discharged into lavatory from the cabin. The fire continued to increase in size and the cabin progressively filled with smoke. The aircraft landed safely, however there were 23 fatalities during the evacuation as the fire “flashed” in the cabin.

More recently in March 1991 an L1011 aircraft flying from Frankfurt to Atlanta carrying 226 people experienced an in-flight fire at 33,000 ft and 200 miles from the nearest place to land. A fire in the cheek area was started by an overheating electrical cable but fuelled by dust, dirt and debris below the floor, flames 2 foot high entered the cabin. This fire was extinguished by injecting three Halon 1211 extinguishers through return air grilles at floor level. The aircraft made a safe landing at Goose Bay, Newfoundland. It is incidents such as this which re-affirm the need to carry Halon 1211 extinguishers on public transport aircraft.

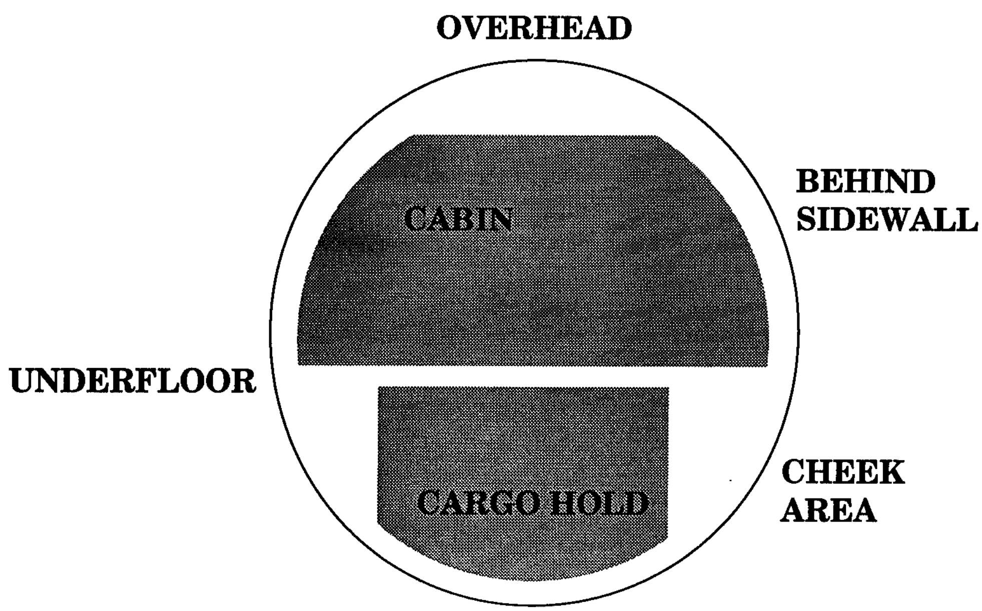

Figure 1 Cross Section of Fuselage Illustrating Hidden Areas

Why change from halon?

The only reason to change from Halon 1211 is due to environmental concerns. Halon 1211 is a member of the group of chemicals known as CFC's, calculations have shown that it will destroy ozone in the upper atmosphere. The Montreal Protocol developed by the United Nations Environment Program and signed by most of the countries of the world caused the production of halons to cease in 1993 for the developed world. Since then trade restrictions have been applied to prevent import of new agent to the developed world. The only source available is existing stocks and recycled material. The use of halon for fire fighting is allowed, however there is legislation in many countries which forbids it's discharge for testing or training purposes.

With these restrictions it is evident that a replacement agent will have to be found. It is only due to these environmental concerns and restriction on availability that a change away from the use of halon is being considered. The quantity of Halon 1211 discharged in flight for the protection of passengers amounts to approximately 1lb per aircraft per year.

How do we ensure no loss in safety?

If the change from halon is to be made without incurring any drop in safety then it is necessary to define the capability of the current extinguishers and ensure that replacements have equal or better performance. This will be achieved by ensuring that the extinguisher is approved by an organisation such as Underwriters Laboratories, Factory Mutual, British Standards Institute or EN - Euro Norm. This will ensure that the extinguisher has a basic defined fire fighting

performance. In addition it is envisaged that the extinguisher must be capable of putting out large fires such as could occur with flammable fluid on an aircraft passenger seat. It will also be necessary to demonstrate that the extinguisher and agent have the capability to extinguish hidden fires. Further considerations will be; ease of use, training and assurance that no additional hazards are introduced.

To ensure that the objectives outlined above could be defined in detail the authorities agreed that both research effort and industry involvement was required. Therefore the FAA set up the International Halon Replacement Working Group. This Group is open to anyone with an involvement in the topic and currently Manufacturers, Airlines, Scientists and Regulators are all represented. As part of this International effort the UK Civil Aviation Authority agreed to pursue the development of a representative hidden fire test method as none existed previously.

This work was contracted by the CAA to Kidde International and is reported in reference 4. The basic methodology was to replicate the volumes, airflow rates and physical restrictions found in the hidden areas of a fuselage. Comparison of figures 2 and 3 will illustrate how this has been achieved. Figure 4 illustrates how the test method can then be used to "map" the effectiveness of an extinguisher and agent by observing extinguishment of the test fires.

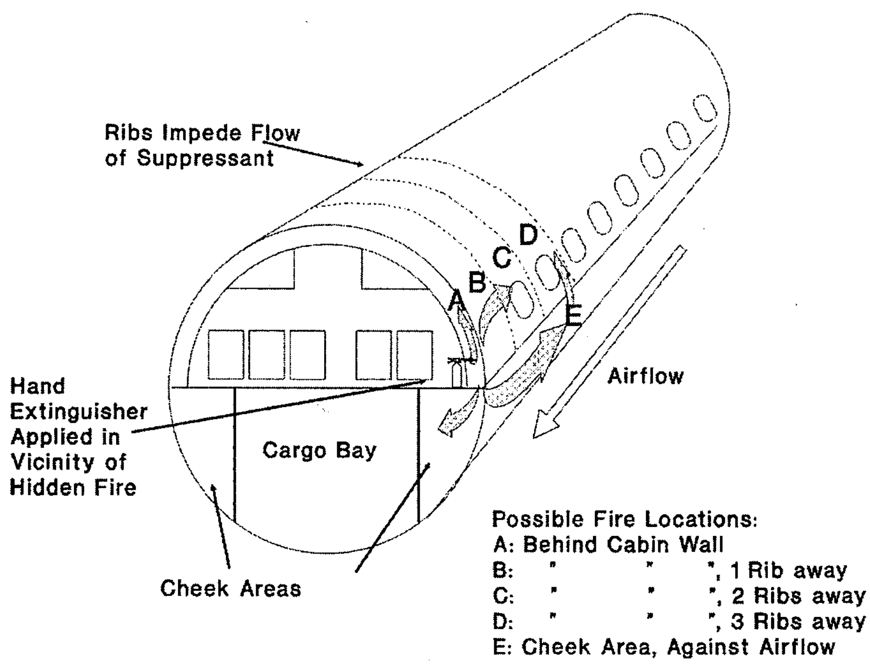

Figure 2 Hidden Areas within the Fuselage

What further efforts can be made to improve fire safety in the cabin?
Prevention of an incident is most desirable and this can be achieved by good housekeeping. I mean by this that the maintenance personnel are vigilant to such things as chaffed cables, the rectification of spurious electrical faults, the prevention of accumulations of dirt and debris and ensuring that there are no loose trim panels behind which objects may get pushed. Obviously the serviceability of extinguishers should be ensured.

Flight Attendants have a role, they must be vigilant at all times, they should check lavatories regularly and in the event of a fire remember their training and be quick and decisive. Whenever possible they should try to get to the source of the fire. Perhaps more training focusing on how to gain access may be appropriate. Are flight attendants too reluctant to risk damaging trim panels?

It is possible to envisage design changes, perhaps the elimination of hidden areas should be a goal for the designers. Large spaces such as the cheek area and the overhead area should be divided into smaller sections to prevent the spread of fire and smoke. This would also aid the correct location of the fire source. Accessibility should be designed into the aircraft, if hidden areas cannot be eliminated then perhaps plug in points for the extinguisher nozzle together with manifolds to deliver the agent should be considered. The installation of heat and smoke detectors located in hidden areas could be beneficial.

Perhaps the extinguisher can be improved, a design which was not critical to orientation would be an advantage. In some incidents the addition of a hose to the extinguisher would also be an advantage.

Summary
Halon 1211 is the best agent currently available for use in handheld extinguishers to be used in the cabin and cockpit. No obvious alternative has yet been identified. However it is evident that a replacement will have to be found. Safety will be maintained if replacement extinguishers achieve the same performance as that currently achieved with Halon 1211. Test criteria are being defined to enable this to performance to be measured. Good housekeeping by the aircraft operator is vital. There are a number of possible improvements for future aircraft designs that could be considered. Finally we should expect the unexpected - A trained person with a good extinguisher can tackle the fire that the designer thought could never happen.

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Abstract

NRC FINDINGS AND RECOMMENDATIONS ON

FIRE RESISTANT AIRCRAFT MATERIALS

Thor I. Eklund
FAA Technical Center

International Conference on
Cabin Safety Research

Atlantic City, New Jersey
November 14-16, 1995

The National Research Council (NRC) through its National Materials Advisory Board has developed a set of formal recommendations to the Federal Aviation Administration (FAA) on research needed to develop aircraft interior materials with improved fire safety properties. The recommendations were based on an assessment of the direction of FAA fire research, an evaluation of the current manufacturing technology for aircraft interior materials, and identification of new and alternate material technologies holding promise for development of highly fire-resistant aircraft cabin interiors. The NRC made research recommendations in the areas of materials, component design and manufacturing, testing and evaluation, and modeling. In materials, the NRC called for fundamental research on polymer combustion, new additive approaches, and development of new thermally stable polymers or modification of existing specialty polymers. The manufacturing research should be oriented to compatibility with current production processes and end-use requirements, low cost, and new design concepts that would offer manufacturing

economies. In test and evaluation, the NRC recommended development of more realistic fire and toxicity test methods and establishment of a materials fire performance data base. Although the modeling recommendations covered a broad spectrum of hazard issues, the NRC emphasized the area of material thermal degradation and behavior under fire exposure conditions. Finally, the NRC recommended a long-term FAA material research program having clearly stated goals, systematic plans, and stable annual funding.

Introduction

In 1993, the Federal Aviation Administration (FAA) awarded a grant to the National Materials Advisory Board (NMAB) of the National Research Council (NRC) for a study project entitled Improved Fire and Smoke Resistant Materials for Commercial Aircraft Interiors. The effort would include an international conference and workshops in 1994 and publication of the conference proceedings and the NMAB committee final report in 1995. The purpose of the present paper is to provide an account of the rationale for and genesis of this project and a summary of significant findings, conclusions, and recommendations arising from it.

Background

In 1991, the FAA produced an **Aircraft Safety Research Plan** in an attempt to structure and relate research projects in the context of goals for reducing aircraft accidents and fatalities (reference 1). Based on domestic airline fatalities over a 10-year period, Figure 1 shows the distribution of the fatalities. From this figure it can be inferred that fatalities can be reduced both through accident prevention and better protection for passengers in impact-survivable accidents.

Starting with the observation that the domestic fatality rate has been steady at two deaths for every 10 million enplaned passengers, the conclusion is that the total number of fatalities in the future will increase in proportion to the growth in commercial operations. Figure 2 shows one scheme that might result in a fifty percent reduction in United States fatalities over a 10-year period that would experience an overall thirty percent increase in annual passenger enplanements.

Similar conclusions can be reached when world-wide statistics are used. Figure 3 from Boeing shows hull loss accidents and rates backwards until 1959 and a projection forward until 2014 (reference 2). With the forecast growth in annual aircraft departures, the annual hull losses can be held constant only by reducing the accident rate by fifty percent over the 20-year forecast interval. At the present hull loss accident rate, the number of hull losses worldwide would increase from approximately twenty per year at present to nearly 40 annually by the year 2014. While Figures 1 and 2 deal with fatalities and Figure 3 addresses hull losses, these statistics do track with one another. Both the FAA and Boeing projections show that accidents and fatalities could rise to unpalatable levels based on growth in air traffic alone. Furthermore, the erratic nature of the year by year accident record would allow this trend to become visible only in the longer term of five to ten years and more. It is likely that such long-term safety trends can be effectively counteracted by long-term safety strategies including research aimed at product delivery many years away.

counteracted by long-term safety strategies including research aimed at product delivery many years away.

In 1988, Congress enacted the Aviation Safety Research Act, which provided the FAA for the first time a clear mandate to undertake such long-term research. Although the subject matter coverage of the Act is broad, the FAA was specifically directed "to assess the fire and smoke resistance of aircraft materials, to develop improved fire and smoke resistant materials for aircraft interiors, to develop and improve fire and smoke containment systems for in-flight fires, and to develop advanced aircraft fuels with low flammability and technologies for containment of aircraft fuels for the purpose of minimizing postcrash fire hazards." The FAA responded to the fire safety aspects of the new legislation by establishing an organizational entity to manage and conduct fire research, by initiating a new fire research program, and by earmarking fire research as a specific identifiable funding line item in the budget process. The 1988 Act provided the FAA with the authority to perform the type long-term research that the cited statistics seem to warrant.

In order to establish constructive research directions that could lead to safety improvements in the long term, the FAA undertook an evaluation of the state-of-the-art in fire technology and used this as a platform to develop a **<u>Fire Research Plan</u>** (reference

3). This plan offers an approach that involves applied research and development leading to new materials, advanced systems, and alternative safety technologies. The plan also includes research directed at advancing fundamental scientific areas needed to support the more applied product development. The long-term aviation fire research falls into six areas: fire modeling, vulnerability analysis, fire resistant materials, improved systems, advanced suppression, and fuel safety. With the exception of fire resistant materials, these areas all represent technologies where the FAA has conducted previous shorter term fire safety research and development or where the agency has undertaken similar research in other fields.

In development of fire safety regulations for aircraft materials, previous FAA research was directed at full-scale fire tests, mock-up tests, and laboratory scale flammability tests. The FAA research was oriented at test method correlations and determination of suitable pass-fail criteria for aircraft materials. The province of development of advanced fireworthy materials fell to the National Aeronautics and Space Administration under the now defunct FIREMEN Program.

Research leading to advanced fire resistant materials represents an entirely new type responsibility for the FAA and represents the significant effects being generated by the Aviation Safety Research Act of 1988. Although the FAA has internally generated specific plans for this research (references 4 and 5), the complexity and breadth of

specific plans for this research (references 4 and 5), the complexity and breadth of material science indicated a need for external guidance. The vehicle for this guidance was the study grant to the NRC. The intent of the FAA was that the NRC findings and recommendations could be used to corroborate, modify, or replace the material research plans formulated by the FAA. The motivation was to identify and pursue the most promising and appropriate emerging material technologies. The wide range of polymeric interior materials used in aircraft is indicated by Table 1 which shows typical materials covering large surface areas and Table 2 which deals with smaller components and assemblies.

NRC Study

Three major elements of the NRC study were the activities of the NMAB committee members culminating in their final report (reference 6), an international conference with invited speakers expert on relevant subject matter, and workshop sessions that followed the conference presentations (reference 7). The NMAB committee performed site visits, selected the conference speakers, analyzed the workshop results, and drafted a final report with committee members developing report sections consistent with their respective areas of expertise. The conference presentations and papers covered aircraft interior design considerations, fire test technology, aircraft fire behavior, fire retardant chemical additives, thermally stable polymers, combustion toxicity, and inorganic and

additives, thermally stable polymers, combustion toxicity, and inorganic and organometallic polymers. The four workshops were on toxicity, fire performance, drivers for material development, and new materials technology. Inputs for FAA fire resistant material research can be derived from the workshop summaries in the conference proceedings (reference 7) or in more direct form from the committee report (reference 6).

Workshops

The summaries presented here are based directly on the presentations at the conference by the workshop chairmen and thus may be slightly different from the written summaries found in reference 7.

In the toxicity area, the recommendations emerging were of a basic nature. In small scale toxicity tests, there are still needs to establish methods that are scaleable and adequately represent full-scale fire scenarios. Overall life threat analyses and models are still needed that also include effects of heat, particulates, and water vapor. Other areas needing further investigation are the applicability of animal data to humans, variability among humans, irritant effects and measurement, and the role of such factors as adrenaline and alcohol on toxic gas models. Recommendations also included research on in vitro hazard analysis and material additives that could act as toxicant suppressants. Additionally, considerations were raised on effects of free radicals in smoke and psychological factors.

considerations were raised on effects of free radicals in smoke and psychological factors. One member of the toxicity group submitted a minority report that included most recommendations of the majority report but added investigation of chronic effects of acute exposures to fire. This minority report recommended against establishing of any fire toxicity requirement by the FAA.

The working group on fire performance parameters developed fire threats that could arise from a variety of aircraft fire scenarios. These fire threats, such as radiant ignition of materials, fuselage melting, and toxic gas exposure times during in-flight fires, were considered in relation to the sample sizes and research processes involved in the development of new materials. From the fire threats, scenarios, and material research, the working group identified recommended research needed to establish material fire performance requirements. These were

1) Computer models for ignition and upward flame spread

2) Computer models on the evolution of compartment hazards as a function of the materials that are burning

3) Bench-scale fire tests to provide input data to the computer models

4) Fire spread in ceiling level smoke layers

5) Fire test methods for small sample sizes

6) Relation of material fire properties to chemical structure and composition

7) Effects of aging on material flammability

The working group on drivers for development of advanced fire resistant materials actually recommended steps that the FAA could take to encourage industry to identify and deploy new materials. This group identified the many types of materials used in aircraft interiors, described overall features that future materials might have as design goals, assessed the ability of industry to meet new requirements for replacing or upgrading these materials, and listed factors that encourage or discourage the development of new materials. The desired future features for materials as shown in Table 3 included total non-burnability, improved burnthrough resistance, uniform specification, property retention under high temperature conditions, low cost, easily cleanable, and aesthetically pleasing. Table 4 shows the drivers for improved materials some of which were research money, process or product simplification, life cycle costs, weight reduction, competition, and actual or anticipated regulations. Table 5 shows

weight reduction, competition, and actual or anticipated regulations. Table 5 shows barriers to new material introduction which included high material qualification costs, product liability costs, intellectual property rights, configuration control requirements, re-engineering and redesign costs, low volume application, downsized industry research, and business cycles.

This working group came up with recommendations that would facilitate the development and use of new fire resistant materials. The first recommendations were aimed at the goals of material research and included the establishment of stable test procedures, specifications, requirements, and acceptance criteria. A second group of recommendations was design based and included the exploration of alternate design concepts and simplified configuration control procedures by the aircraft manufacturers. A third group was in the area of cooperation and communication and included joint partnerships between and among agencies, industry, and universities and emphasized communication between the technical innovators and the end users. These priority suggestions are shown in Table 6.

The working group on new materials technology started out with a statement of the state-of-the-art of fire resistant materials in aircraft interiors and went on to list fire performance goals. The latter included reduction of heat release to zero, minimized toxicity products, and an understanding of behavior of materials during fire involvement.

toxicity products, and an understanding of behavior of materials during fire involvement. The materials working group recommended research be done to develop a basic understanding of char characteristics and char formation including the effects of atmosphere, heating rate, additives, coatings, and molecular structure. While recommending near-term research to modify engineering polymers (polycarbonate, nylon, phenolic, polyethyleneterephthalate) for improved fire resistance and to understand thermal degradation mechanisms of specialty polymers (PEEK, PEI, PPS and polysulfone), the working group recommended development of entirely new materials for long-term improvements. Research to develop new, high-performance, thermally stable materials was recommended to include organic-inorganic systems, copolymers, polymer blends and alloys, glasses, and ceramics.

Committee Recommendations

The NMAB committee, through its own study process, produced a final report (reference 6) that provides a comprehensive assessment of the issues of fire and material flammability in civil aircraft. This report details issues associated with design and function requirements of aircraft materials as well as technology requirements for the development of advanced fire resistant materials. The committee concludes that long-term focused research can lead to significant improvements in the flammability characteristics of aircraft interior materials and suggests the three research directions

characteristics of aircraft interior materials and suggests the three research directions shown in Table 7. The final report identifies a wide variety of research opportunities and concludes with fourteen individual recommendations.

Five of the recommendations are aimed at modeling and fundamental understanding of polymer degradation and combustion. Included within these five are char formation, molecular modeling of thermal degradation, modeling of fire growth and hazard assessment, physical behavior of polymers during thermal degradation, and development of a database of fire performance properties. Two recommendations are directed at developing small-scale fire performance and toxicity tests and verifying their validity on increasing scale up to full-scale tests.

Two recommendations deal with at the development of new materials -- one being additive approaches and the other being entirely new thermally stable polymers or modifications to existing specialty polymers. Three recommendations related material research to manufacturing processes and end-use requirements. These include compatibility with processing and tooling, low cost processing, innovative cabin designs that reduce material costs, and performance and aesthetic demands of aircraft interior applications.

The final two recommendations deal with the management of long-term research. One calls for establishment of clear agency goals, systematic plans, and stable financial commitment. The other calls for coordination with other Federal agencies conducting related research. Beyond these fourteen highlighted recommendations, the NMAB concluded that research was needed in a wide variety of additional areas including fuel safety, in-flight fire containment, suppression modeling, and many aspects of fire toxicity. In this larger sense, the NMAB-recommended research is nearly as broad as the FAA Fire Research Plan (reference 3).

Current FAA Research

Of the six technical areas delineated in the Fire Research Plan, the FAA presently is pursuing the one on fire-resistant materials with emphasis on synthesis, characterization, processing, and modeling. The research is aimed at (1) fundamental investigations of polymer degradation and decomposition through molecular modeling, phenomenological physical modeling, and thermodynamic, kinetic, and transport analyses, (2) synthesis of new thermally stable polymers, some of which employ specialty polymers in their formulation, and (3) polymers involving inorganic building blocks such as nanocomposites, organic-inorganic polymers, or inorganic polymers. A small portion of research does involve existing engineering polymers mainly to elucidate physics of

decomposition and the effectiveness of fire retardant chemicals under severe thermal exposure conditions.

In the fundamental research area, one-dimensional models are being developed that include heat transfer, char formation, decomposition kinetics, and combustion heat release in order to predict polymer ignitability and burning rate. Molecular models are being developed to predict polymer degradation physics at the molecular level to serve as an aid in selecting candidate systems with enhanced thermal stability. Some new thermally stable polymers include polybenzoxazines; polychlorophosphazine elastomers; triazine resins; phosphine oxide copolymers of PEEK, PEK, PPS, and PI; and oligomeric and polymeric alkyne-functionalized polyphenylenes and fullerenes. Some of the work using inorganics includes the polysialates, inorganic-organic polymer hybrids synthesized from silica and glycols, and polymer-silicate nanocomposites. The polysialates represent an endpoint in fire-resistance as they release virtually no heat under severe fire exposure conditions. They are also inexpensive in terms of raw material and processing. Their utility for aircraft applications, however, has yet to be determined.

Conclusions

The NRC has completed a study on Improved Fire- and Smoke-Resistant Materials for Commercial Aircraft Interiors. The NRC concluded that long-term, focused research in fire-resistant polymeric materials can lead to significant improvements in fire-performance and safety. The NRC recommends a broad research program including toxicity testing, fire modeling, database development, and mechanisms of thermal degradation along with work on modification and synthesis of polymers. The material development work would include the modification of existing engineering polymers, modification of specialty polymers, and development of new, high-performance, thermally stable materials running the gamut from polymer blends through organic-inorganic systems to glasses and ceramics.

The FAA research program maintains a high degree of fidelity to portions of the NRC recommendations but is presently narrower in scope. The FAA program is focused primarily on fundamental research on high temperature degradation and flammability of materials and on modification and synthesis research weighted heavily towards the development of new, high-performance thermally stable materials. Nevertheless, in light of the conference workshops, it appears the introduction of advanced fire resistant materials into the commercial jet fleet will be contingent on the three factors shown in

Figure 4. These are finding new materials, overcoming the barriers to implementation, and accommodating the stringent weight requirements.

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FIGURE 1 - AIRCRAFT FATALITIES DISTRIBUTION

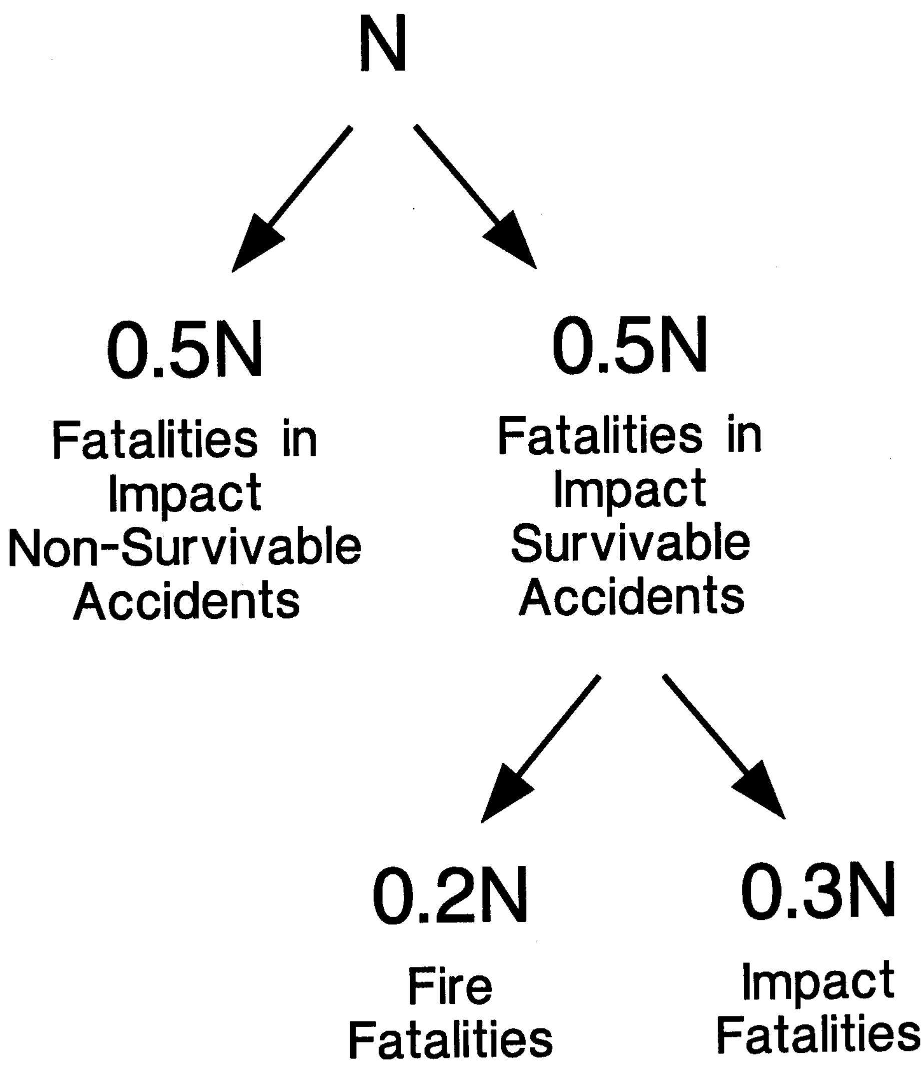
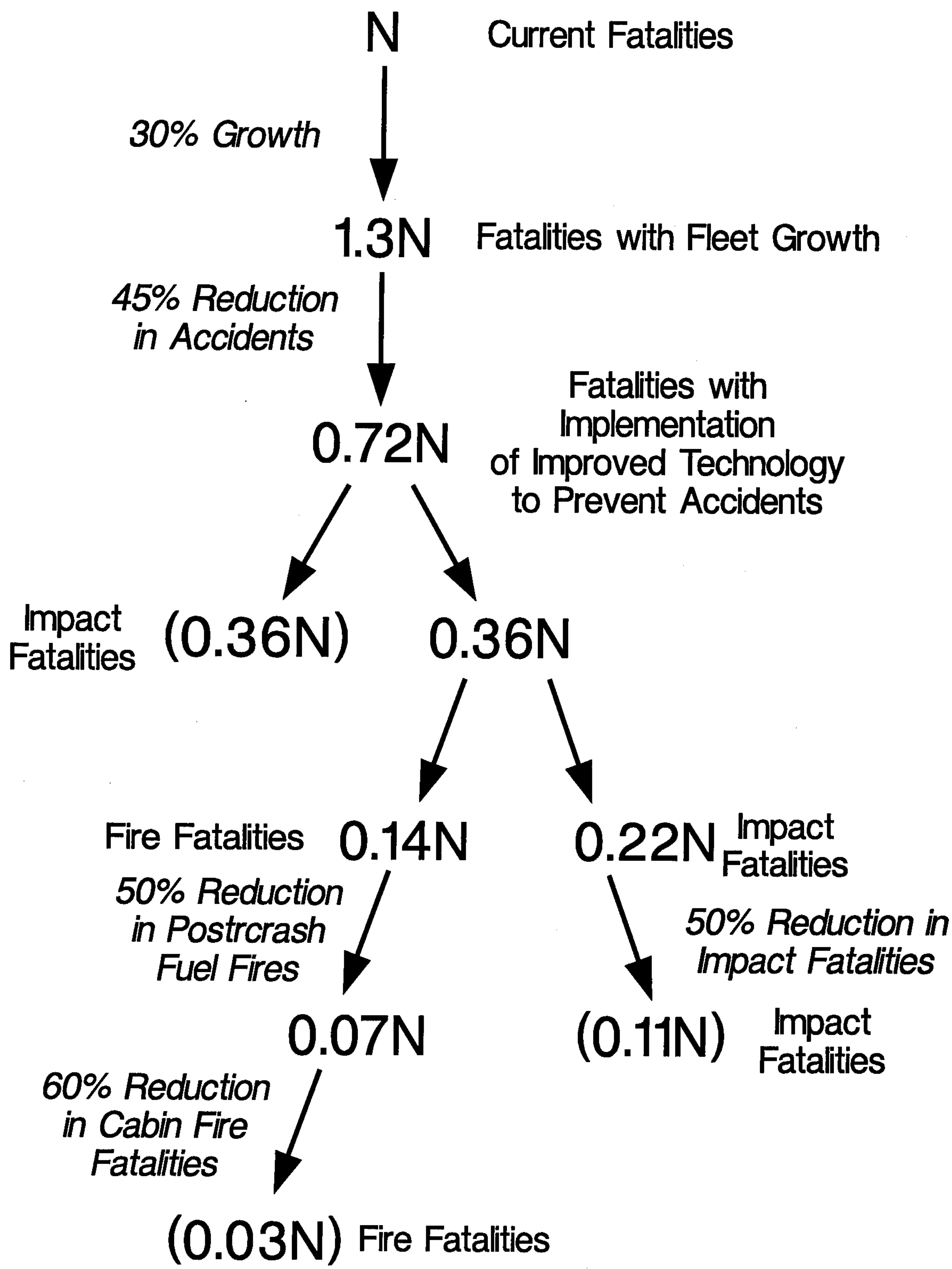


FIGURE 2 - ONE STRATEGY FOR FATALITY REDUCTION



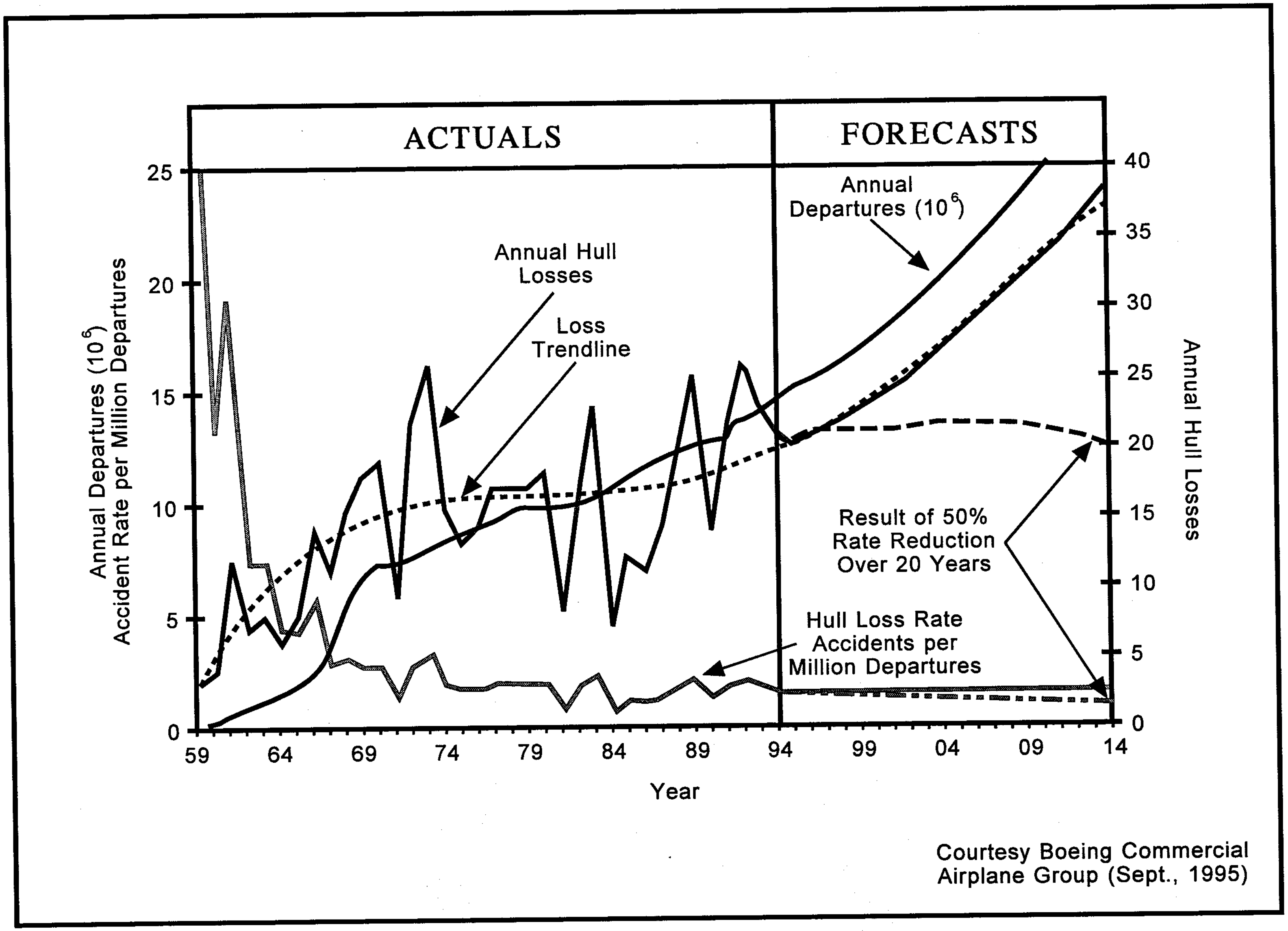


FIGURE 3 - WORLD-WIDE AIRCRAFT HULL LOSSES, RATES, AND PROJECTIONS

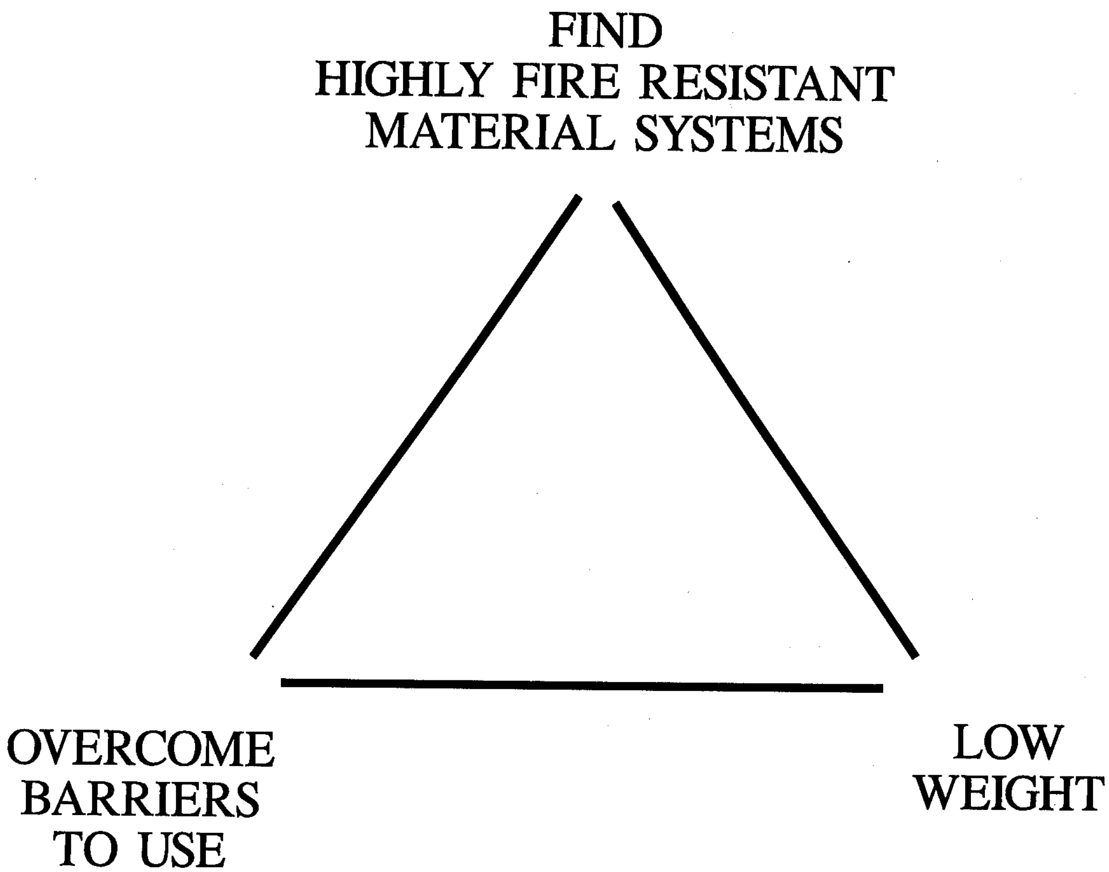


FIGURE 4 - Focal Points for Achieving Fire-Safe Aircraft Materials

TABLE 1 -- LARGE SURFACE INTERIOR MATERIALS

Dado Panel
- Phenolic Glass or Phenolic Carbon on Nomex® Honeycomb
- Wool, Nomex®, or Thermoplastic Surface

Upper Sidewall, Partitions, Stowage Bins
- Phenolic Glass or Phenolic Carbon on Nomex® Honeycomb
- Thermoplastic Decorative Layer
- Urethane Foam Close-Outs and Inserts
- Silicone and Urethane Gap Fillers

Placards
- Urethane and PVC

Flooring
- Epoxy-Glass or Epoxy-Carbon on Phenolic Nomex® Honeycomb with Urethane Close-Outs.
- Mylar® Film Over Galley and Door Panels
- Wool or Nylon Carpet
- Nomex® Pad Carpet Underlay
- Double-Backed Tapes for Floor Adhesion
- PVC Mats And Coverings on Galley Floors
- Urethane Seat Track Covers

Insulation Bagging
- Nylon Reinforced Polyester
- Tedlar
- Polyimide

Insulation Batting
- Fiberglass
- Urethane Foam
- Polyethylene Foam
- Polyvinylnitrile Foam
- Polyimide Foam

TABLE 2 -- INTERIOR COMPONENT MATERIALS

WINDOWS

- Pressure Pane - Stretched Acrylic
- Safety Pane - Cast Acrylic
- Scratch Panel - Polycarbonate

LIGHTING COVERS

- Polycarbonate

SEAT ASSEMBLIES

- Wool, Wool/Nylon, or Leather Upholstery
- Polybenzimidazole or Nomex®/Kevlar® Blocking Layer
- Urethane Foam Cushions
- Polyethylene Flotation Foam
- Thermoplastic Skinned Polyethylene, Polycarbonate, or Urethane Foams For Trays and Armrests

PASSENGER SERVICE UNITS

- Aluminum
- Phenolic Glass or Phenolic Carbon
- Thermoplastics (PEKK, Ultem®, Radel®)

AIR DUCTING

- Phenolic Glass, Epoxy Glass, Polyester Glass, or Silicone Glass
- Polyisocyanurate Foam
- Nylon
- Nomex® Felt
- Polyimide Foam
- Aluminum

HOSES

- Silicone
- Nylon
- Urethane
- PVC
- Tygon

TABLE 3 -- MATERIAL PERFORMANCE GOALS

- Uniform Requirements for all Interior Parts
- Improved Burnthrough Resistance
- Totally Non-Burnable
- Retention of Mechanical Properties
- Economically Viable
- Aesthetically Pleasing
- Low Smoke and Toxic Product Emission
- Easily Cleanable

TABLE 4 -- DRIVERS TO DEVELOPMENT AND IMPLEMENTATION OF MATERIALS

- Return on Investment, Market Share
- Regulation, U.S. Congress, Global Standards
- Lowered Maintenance, Life Cycle Cost Reduction
- Product Improvement, Weight Reduction
- Research Funding
- Product or Process Simplification
- Need
- Alternate Markets or Uses

TABLE 5 -- BARRIERS TO DEPLOYMENT OF NEW MATERIALS

- Low Business Volume, Low Production Level
- Cost Associated with Engineering Change to an Aircraft Design
- Expensive Quality Control Requirements
- Cyclical Nature of Aerospace Economy
- High Material Qualification Costs
- Downsizing of Research Infrastructure
- High Cost of Current Generation Thermally Stable Polymers
- Lack of Industry Direction For Use of Government Research Funds
- Product Liability Costs
- FAA Research Funding Levels
- Reduced Aircraft Manufacturing Design Cycle
- High Risk Research, Low Likelihood of Utilization

TABLE 6 -- SUGGESTED FAA PRIORITIES

- Establish Goals and Requirements
- Establish Stable Test Procedures and Equipment
- Improve Communication Between Technology Developers and Users
- Establish a Forum for Exchange Of Ideas and Technology
- Provide Funding to Industry and Academia
- Explore Alternative Design Principles
- Explore Simplified Configuration Control
- Explore Cooperative Ventures with Other Government Agencies
- Find Alternate (Additional) Application Uses for New Materials

TABLE 7 -- NRC MATERIALS RESEARCH DIRECTIONS

- Modification of specialty polymers including thermoplastics such as polyetheretherketone, polyetherimide, polyphenylene sulfide, and polysulfone and thermosets such as cyanate esters, bismaleimides, polyimides, and polybenzimidizole.

- Development of new, high performance, thermally stable materials including organic-inorganic systems, copolymers, polymer blends and alloys, and glasses and ceramics.

- Modification of existing engineering polymers including thermoplastics such as polycarbonates, nylons, and polyethyleneterephthalate and thermosets such as phenolic and polyester.

BREAKOUT SESSION SUMMARIES

Thursday, November 16, 1995

Breakout Session on Evacuation

16 November 1995

Chairman: ***Jean-Paul Deneuville*** *(STPA/N)* / ***Claude Lewis*** *(TCA)*

Introduction

The session was opened with a brief statement, by the Chairman, of the objective of the meeting: to identify areas/tasks of potential research to improve evacuation safety (and, as much as possible, attempt to apportion some degree of priority to these).

The first part of the session was dedicated to reviewing/answering 'questions to the speakers' which could not be addressed in the general session. The questions raised were essentially of a clarifying nature and are accordingly not discussed in this report; however those elements pertaining to potential research are incorporated therein.

The second, and main, part of the session was devoted to the development of research action proposals. The approach taken was essentially of the 'brainstorming' type (periodically 're-focussed'), where ideas/suggestions/proposals submitted by the participants were discussed and explored in a structured yet open/flexible format.

Although specific priorities could not be assigned to the various tasks/projects, it was agreed that those having high benefit-to-cost ratio or potential for early implementation should be pursued more urgently. The summary which follows has been organised and is presented in the broad order of importance perceived from the discussions, and does not establish a definitive priority.

Discussion Summary

It was considered that the evacuation 'equation' comprised three basic interrelated elements: the aircraft, the crew and the passengers (Ref. *Slide 1*). The discussions covered a wide range of issues pertaining to those three elements but, to a large extent, tended to concentrate on human behaviour aspects.

The following summarizes the discussions and reflects the identified areas of potential evacuation research (Ref. *Slide 2*)

- Concerns were expressed that flight attendant duty time was such that they were often fatigued by the time flights were close to arrival, but they still had to be

prepared for every safety-related eventuality. It was recommended that information on safety efficiency versus duty time be acquired/developed.

The benefits of crew resource management was also stressed, and it was suggested that this needed to be researched further.

There were concerns expressed on the fact that operators had different evacuation training methods, and it was suggested that one standard procedure should be defined for all airlines. It was noted that flight attendant training methods generally needed to be improved to optimise evacuation performance. Concern was expressed that safety procedures are often taught through computer-based training, and that decision-making under stress was thus not being experienced. It was recommended that research was needed to establish the limitations of computer-based training against 'hands-on / command and control' training.

It was felt that marketing considerations often tended to dominate training, and it was suggested that methods of improving effectiveness through operator organisational changes should be investigated.

- The issue of Type III exits was extensively discussed.

  It was proposed that the benefits of positioning flight attendants at Type III exits (to operate the exits and 'direct' the evacuation) should be investigated by comparing the evacuation performance under that condition with that where the exits are operated by passengers ('naive' subjects), with no flight attendant in the area.

  Concern was expressed that dual pairs of Type III exits in close proximity may not provide twice the evacuation capability of single pairs. It was suggested that this needed to be investigated.

  It was proposed that research should be undertaken to assess the effects, on evacuation, of visibility reduction due to smoke, under both 'competitive' situations simulating panic, and the more controlled and orderly 'co-operative' scenarios.

  It was suggested that FAA CAMI and Cranfield University should work more closely in order to develop common research protocols which would allow more direct comparison of research results and data from the two sources to be complementary.

  It was noted that underwing Type III exits (often found on smaller transport category airplanes) present an additional problem which should be explored: that of passengers needing to jump a distance to the ground from the exit sill (rather than

from the wing), and it was suggested that the benefits of a small slide should be investigated for such configurations.

- It was noted that most of the safety research to date had focused on the first two elements of the evacuation 'equation' (the aircraft and the crew), while relatively little effort had been directed towards improving the ability of passengers to help themselves in the event of an emergency evacuation.

  It was pointed out that the safety briefing was made at a time that was stressful for many people, particularly infrequent flyers (i.e. just prior to takeoff), and that perhaps less but more 'focused' information should be given. Further, it was suggested that alternative methods of providing the information should be considered, possibly in an interactive manner using the personal video screens increasingly fitted in cabins.

  It was further noted that, for many passengers, just being at an airport was stressful, and that general concern about travel arrangements etc... might result in very little knowledge from the safety briefing being retained. It was suggested that the potential benefits of passenger safety 'display stands' at airports, to provide information to passengers and allow them an opportunity to become familiar with the safety features of aircraft cabins, should be investigated.

  It was suggested that it would likely be very beneficial to perform a broad study of all aspects of passenger awareness of safety matters and of passenger perceptions of what is needed to enhance safety.

- Some time was spent discussing the 90-second evacuation demonstration, with suggestions being made to pursue activities towards reducing their number and enhancing the safety of their conduct, such as the use of partial tests and ramp/platform tests, and increased use of modeling and analysis. It was felt that the inherent risks associated with certification evacuation demonstrations would become even more significant as aircraft became larger, and that computer modeling could provide a means to assist in assessing the evacuation capability of an airplane.

- It was agreed that computer evacuation (and fire) models would be increasingly valuable tools for gaining an understanding of the safety implications of cabin configurations. It was however highlighted that extensive data was needed to pursue the development and validation of the models, and manufacturers and operators were asked to support requests from modelers for data and information on emergency evacuation certification demonstrations. It was also suggested that non-aviation sources of evacuation data (e.g. buildings, ships, ...) should be sought to improve the fidelity of models.

It was noted that, for reasons of safety, it would always be difficult to gather certain types of data, and that one of the benefits of modeling is that a range of conditions can be considered in exploring the evacuation capability of a cabin configuration.

It was indicated that models needed to address both 'competitive' (disorderly) and 'cooperative' (more orderly) scenarios.

- It was noted that smaller transport category airplanes presented particular design/safety problems/considerations (e.g. narrow aisle widths, low ceiling, short seat pitch) that were very different from those of larger airplanes, and that resources needed to be assigned to address these. Also, specifically, concern was expressed relative to the method and reliability of exit/door operation.

- It was suggested that work needed to be done towards improving the 'user-friendliness' of evacuation systems. Specifically, it was suggested that the effect, on evacuation, of sill height (incl. criteria for assist means) and slide angle/perception should be investigated.

  Also, it was suggested that the issue of rescue, which involves non-aviation organisations, needed further review and possibly improvements (e.g. in the area of ditching and external rescue markings) to enhance evacuation/survival.

- It was suggested that better guidelines needed to be developed on the management of mobility-impaired passengers, aged passengers and minors. It was noted that some flights include significant numbers of aged passengers (while, similarly, some flights include a higher-than-average number of minors) and that more information needed to be acquired/developed on how evacuation performance was affected by the presence of such a 'population', and how this performance might be improved.

- A number of suggestions were made that research should be done towards generally improving the 'cabin environment' (e.g. aisle and exit design/ergonomics) to enhance evacuation.

- Exterior threat assessment was considered to need improvement. It was pointed out that it can be very difficult for flight attendants to view external conditions to ascertain the safety of the evacuation path prior to opening exits as viewing windows are typically small, with condensation/rain/darkness combining to make even a simple decision (such as: "Is the aircraft still moving?") very difficult. Research on vision enhancement devices and improved lighting was accordingly suggested.

- It was considered that information from survivors was extremely valuable, and that acquisition/gathering of such data, though extremely 'sensitive', could be improved, possibly through the development of a standardized questionnaire.

- It was suggested that video cameras should be installed in cabins to record events during an accident(/incident). Although there was no specific research identified on the subject, it was agreed there was a need to investigate associated legal and ethical issues.

It was agreed that it was not possible, with the data and within the timeframe available, to assign specific priorities to the various research areas/tasks, other than to make a general decision that those that had a high benefit-to-cost ratio or were likely to make an early safety improvement should be given priority.

Conclusion

It was generally felt that the session had been very worthwhile and productive, but it was commented that the Authorities did not seem to show great enthusiasm and positive commitment to making improvements, and frustration was expressed that regulatory action mandating known safety improvements often took too long in being implemented. The Chairman stated that he, the Authorities and the speakers/researchers were committed to making every effort to improve safety, and that the FAA/TCA/JAA Cabin Safety Research Program was evidence of that commitment.

Closing

The Chairman thanked the participants for their contribution, and adjourned the session.

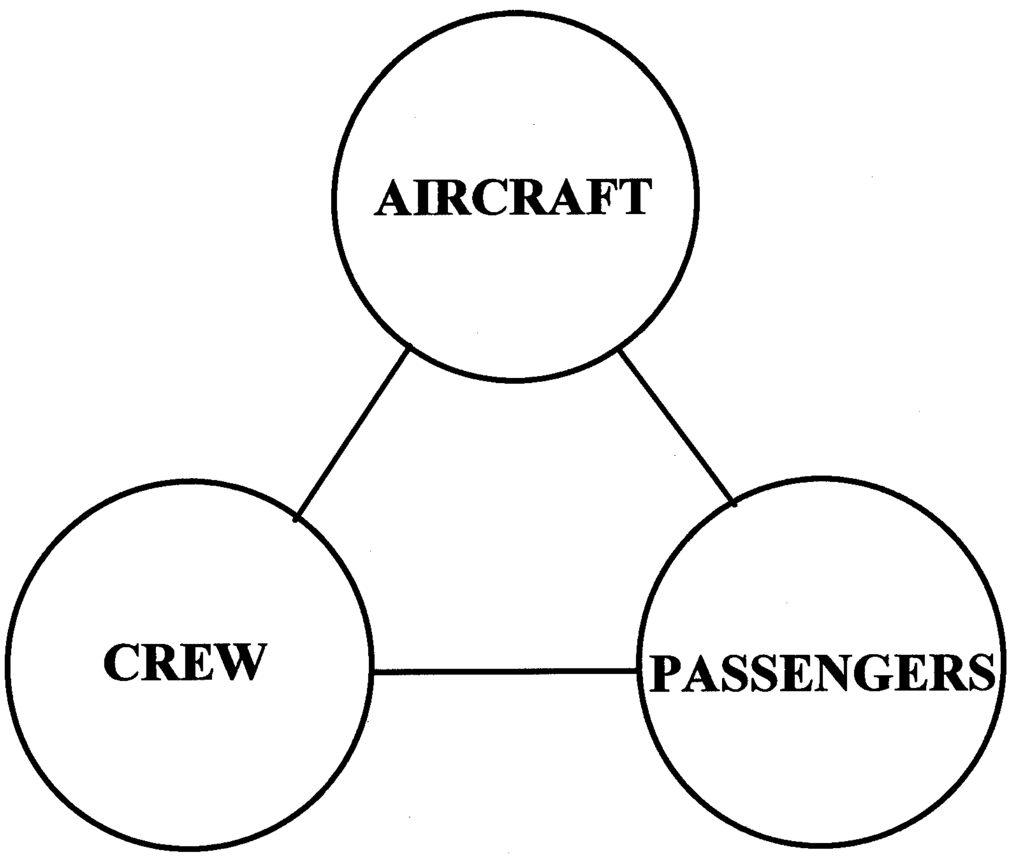
The following slides, which summarize the preceding, were presented by the Chairman in his report to the general assembly:

- *Slide 1 - Evacuation 'Equation'*
- *Slide 2 - Main Areas of Potential Evacuation Research*

Slide 1

Evacuation

Evacuation 'Equation'



Slide 2

Evacuation

Main Areas of Potential Evacuation Research

- Evacuation Management / Crew Performance/Procedures/Training
- Type III Exits
- Passenger Performance/Education/Briefing
- Certification (90-Second) Evacuation Demonstration
- Computer Modeling of Evacuation (& Fire)
- Design Considerations for Smaller Transport Category Airplanes
- 'User-Friendliness' of Evacuation Systems (e.g.: Sill Height Problems)
- Mobility of Impaired Passengers, Aged Passengers and Minors
- Cabin Environment (e.g.: Exit Design)
- Exterior Threat Assessment
- Survivor Information
- Data Acquisition ('In-Cabin' Cameras)

International Conference on Cabin Safety Research
Atlantic City
November 14-16, 1995

Report of the Crash Dynamics 'Breakout' Session

1. Outstanding Questions from Presentations

Some written questions had been submitted regarding the crash dynamics presentations.

(i) Airbags.

A comment was made that airbags in cars are an integral part of the occupant protection system along with the restraint, interior design, etc. The Simula representative agreed but explained that the commercial aircraft application being developed at the moment was a specific application to address the front bulkhead only. Any further more general use in aircraft would need to be integrated into the cabin environment with other occupant protection features.

Another comment concerned the compatibility of the airbag with the brace position and questioned whether the passengers in the affected seats could be relied on to be in the seated upright position at impact instead of a brace position. It was explained that, in common with the '16g' rule, the airbag solution assumes for the purposes of certification that the occupant is in the upright position. However it is also confirmed by testing and analysis that the airbag does not constitute a hazard to passengers in a brace position.

(ii) Other Issues

One question received asked whether restraint systems for pilots and cabin attendants had been tested and what were the results. The only appropriate answer was that the restraints are tested either statically or dynamically according to the airworthiness standard applied to a particular aircraft.

A paper was presented by Dr. Takao Kawakita of IREA Air Safety, a group representing the bereaved families from the Japan Airlines B747 accident of 1985. The paper gave details of a research programme initiated by the Japan Ministry of Transport to investigate the potential benefits and costs of rear facing seats and seats provided with upper torso restraint. After hearing the paper the group agreed to consider these issues in the main 'breakout' discussion, (see item 2.(iii)).

A paper was presented by Ulla Bolter of the Union of Commercial Salaried Employees (HTF). This explained the need for improved design of flight attendant seats, not only with respect to crashworthiness, but also occupant protection in normal operation. This issue is covered in the main 'breakout' discussion (see item 2.(iv)).
A written submission from the Association of Flight Attendants recommended research into rear facing seats for passengers in certain areas of the cabin and a component test for Head Injury

Criteria (HIC). Both these issues are addressed in the main 'breakout' discussions (see items 2.(iii) and 2.(vi)).

2. Discussion on the Needs for Future Research

The Chairman outlined his proposals for the form of the presentation to be made at the main conference concluding session. After some general discussion it was agreed that rather than an extensive list of separate technical items to be described and prioritised, a smaller number of 'systematic' areas of crash dynamic related issues should be identified.

The following summarises these discussions.

(i) Cooperation of Authorities, Manufacturers, Research Agencies, etc.

The group were of the firm opinion that there is a wealth of information held by various organisations involved in research. Much of this is retained under the guise of proprietary data. Although it is recognised that there are commercial and legal restrictions to publication of some information, there was strong agreement that much more data could be made available.

There had been much talk concerning data bases during the conference presentations. There should be coordinated efforts to publicise and make these available.

There was agreement that existing modelling techniques are probably adequate for the current research needs of the industry. However more cooperation is required to validate data and share experience on the use of models. Coordination with the automotive industry should also be pursued to increase the knowledge base.

This coordination activity was seen as of a high priority, particularly in view of the increased international participation that will be required in future major research programmes.

(ii) Aircraft/Seat Interface

The group was reminded that the FAR/JAR 25.562 ('16g') rule included a systematic approach covering basic structural integrity, occupant injury, and evacuation considerations. One factor had been the compatibility of the rule with existing aircraft structure.

Following some accidents where the seats had remained intact but the floor had failed, investigator comment had been made that the floors should be designed to a 'tougher' standard. Proposals to consider such a change to requirements would require extensive research to investigate the potential benefits and costs. Additional research to introduce new rulemaking would also be needed.

The group considered that although preliminary work could be conducted to investigate this possibility, the extensive cost of research and subsequent rulemaking and the unlikelihood of achieving an adequate safety benefit justifies a low priority to this issue.

(iii) Rear Facing Seats/Upper Torso Restraint

Although these two subjects could be considered as separate, the group considered that in view of their similarities with respect to costs of introduction and also the 'passenger appeal' factor, a coordinated study of both comparing the costs/benefits may be the best approach.

However, in view of the expected conclusion that the safety benefits would have to be massive to justify introduction on an industry wide basis, it was considered that a high priority could not be allocated to research on these items.

(iv) Cabin Crew Seats

The group heard information that some cabin crew seats in service may be causing lower back injuries to cabin crew due to hard landings in normal operation. The majority of group members were unaware of this and considered that, in addition to the concern in normal operation, this could indicate that the seat may not give adequate protection under emergency landing conditions.

It was decided that this specific problem should be investigated and that the results could be used to conduct further research into cabin crew seat injury protection. In view of the criticality of protecting cabin crew in relation to the evacuation process, research may be justified in addition to the provisions of the existing dynamic seat evaluation rule..

(v) Cabin Design

The group concluded that instead of being a series of separate items, the cabin could be considered a safety system in its own right and therefore be subject to a systematic approach. Particular attention has recently been addressed to retention of overhead bins and their containment capability in emergency landing conditions. However other factors such as the normal loading, (i.e. the amount of carry-on baggage permitted), are also relevant in the overall context of the integrity of the cabin interior.

An approach was therefore considered to be necessary that takes into consideration not only relevant aspects of design and operations but also the passenger appeal and convenience factors involved. It is only by such a comprehensive study that the realistic prospects of achieving any significant changes on an international basis can be determined.

The continuing investigation into overhead bin retention and latching should be given a high priority based on evidence from recent accidents and the comparatively short term benefits. Other activity related to the overall subject may however only merit a medium priority with regard to the level of work required to be performed and the uncertain prospect of significant benefits.

(vi) Occupant Injury

There has been much discussion concerning occupant injury including that relating to the investigation of some accidents. Injuries to lower legs and neck are two examples which could possibly be candidates for further investigation.

However, although there is a strong case for examining further possible progress in this area, the difficult experience of implementing the existing rule, particularly the part related to HIC, lead the group to express caution. This experience may illustrate the potential problems which may be associated with implementing a systematic, multi-faceted requirement. The group considered that a high priority could not be given to extending the injury criteria requirements unless a significant positive cost/safety benefit could be identified at an early stage.

The existing HIC requirement has resulted in continuing investigation into determining a small scale component test in place of the full scale tests currently being used. Although primarily driven by cost reduction, the group considered that the development of component test techniques should result in the opportunity for many improved head injury protection characteristics on all potential head strike areas in the cabin. A high priority should be given to these efforts.

One occupant injury topic that frequently arises is brace position. The group considered that, although continuing efforts should be made to standardise the recommended brace position, enough basic research has already been conducted and further work is not justified because of the limited benefit.

(vii) Test Facility Harmonisation

The conference presentations had included information on existing and planned impact test facilities throughout the world. The group considered it essential that, in view of the extensive research involving several countries which may take place for future regulation changes, efforts be made to ensure consistency of testing techniques and interpretation of results. It was noted that a process of harmonisation between crash test facilities had taken place to some extent regarding the '16g' activities, but this had been driven primarily by commercial considerations. In areas of pure research, new efforts may be required to ensure adequate interchange of experience, information and results.

This activity will depend on the need arising as research progresses but on principle should be given a high priority.

viii) Composite Aircraft/Novel Designs

There are two particular prospective developments which may have an impact on crash dynamic issues, namely increased use of composite structures, and very large aircraft.

In the case of composites the airframe may become less energy absorbing in its characteristics compared with conventional metal structures. Almost complete composite airframe structures already exist in smaller aircraft. Although such extensive use may be further into the future in the case of large transport aircraft, it is recognised that existing airworthiness requirements do not take account of these potential changes.

The new very large transport aircraft may also give rise to issues not addressed by existing requirements. Although in some aspects larger aircraft may have improved crashworthiness characteristics, for example providing an increased depth of crushable structure beneath the cabin floor, novel features such as lower deck seating or factors related to extra wide cabins may need particular consideration.

The group decided that, although future developments may need special consideration and could present problems for manufacturers and authorities regarding their crashworthiness acceptability, there was no justification for any short term research work to address these issues.

(ix) Operations

It is not usual to relate operational aspects to a technical subject such as crash dynamics but having already appreciated a connection regarding overhead bin loading as described in item (v), the group considered that there may be opportunities for further study. Changes to operational procedures in the cabin can often be introduced relatively quickly with minimal cost and on a more local basis than airworthiness or design changes.

One particular crashworthiness aspect which may prove profitable to examine is that of inadvertent entry into water, for example departure from a waterside runway during takeoff or landing. In addition to the study of whether the aircraft design could better protect against water ingress in such an event, there was general feeling that existing operational procedures may be under-developed and therefore inadequate or inappropriate.

In view of the relatively low cost of investigation and ease of introduction of any operational changes, the group considered that a high priority should be given to this area of study.

(x) Infant Restraint

Although very specific, the group considered it appropriate to include this as a separately identified issue because of the high political profile. As discussed in previous forums, the cost/safety benefit analysis arithmetic does not merit any further research, but the group recommended that efforts should be made to harmonise international policy within existing practices to attain the optimum available. The technology available in the automotive industry should also be monitored to ensure that the required compatibility be retained. An example of this is the 'Isofix' infant seat which plugs into purpose built receptacles in car seats.

16 November 1995

Fire Safety Breakout Session

The breakout session was organized to have an initial question and answer period, where the speakers would address questions for which there was insufficient time during the main, general sessions. Questions were directed to Gus Sarkos, Tim Marker/Darren Dodd, Nick Povey and Wolfgang Lampa. Each speaker addressed the questions that were submitted in writing, and there were also follow-up questions asked during the session.

Questions Sessions:

* There is an interest in waterspray, and where this project is going. It was explained that there is currently no work on a cabin waterspray system, but that consideration of water as a halon replacement was underway.

* There is continued interest in smokehoods, or some other such device that provides breathing protection in the presence of toxic gases. The FAA philosophy regarding limiting flammability, and thereby limiting toxic gases was presented. There is still a concern that an adequate risk and benefit analysis was not done, since too many assumptions were made to assess the potential detriments associated with smoke hoods To this end, there were also general comments on the direction of research i.e. smoke and toxicity, versus material flammability.

* hazardous goods protection (unlabeled)

* Hidden fires and the methods for fighting them was also a subject of high interest. There were many questions and discussions regarding the sources of hidden fires and the means for addressing them, i.e., design, materials maintenance.

* Methods for, and results of, burn-through tests were discussed in detail. Many people felt that this was a very important issue, although there were also written comments indicating that the work might be misguided, if windows are not being addressed. The various test methods were discussed (medium scale versus full-scale) and there possible future applicability to all composite fuselages. In addition, some of the findings and their influence on future work were discussed.

* There were several questions on the developing Halon hand held extinguisher test methods, and how these would be implemented into other standards, such as

underwriters laboratories. Discussion on this topic also related to hidden fires above.

* The issue Flight Attendant uniforms, and the lack of flammability standards and styles (long sleeves etc.) requirements was brought up. Some people felt that there should be research into this to determine the feasibility of developing such standards. Others felt that the knowledge already existed, and there was no need for research.

<u>Discussion Session:</u> The approach used in this session was to solicit input from the attendees, in a kind of brainstorming session. Any research topic that was brought up was listed in a master record. Following this listing, each item was assessed for relative priority by the entire group. A ranking of "high", "medium" and "low" was possible for each person, for each item. In addition, a fourth category, indicating that research should NOT be performed was possible, to allow for totally dissenting views. Not everyone was present for the whole session. Many persons who brought up items were not available when the tally's were taken. The group initially consisted of representatives from airframe, material, and component manufactures; operators; flight attendant associations; survivors' groups; the aviation authorities; as well as military and rail representatives.

** Fire safety is generally categorized into three approaches: Prevention; Detection; Suppression and management. The general focus of items turned out to be on suppression and detection versus prevention.

* There were some general comments regarding the course research (any research) should take, as well as how it might eventually get implemented into service. There was a feeling that regulation changes are required to implement any improvement in today's climate, and that general improvements would not be made unless mandated. It was difficult to judge how pervasive this feeling was.

In addressing any safety design issue, it's actual benefit versus its potential cost should be considered. This applies to things that are already requirements, as well as future requirements.

* In keeping with the theme of the cabin safety program plan, a global perspective is needed to take account of other research (outside the cabin safety area) that may have an impact on cabin safety research. This is particularly true where there may be no current connection between research programs. For example, the effect of corrosion inhibitors on burn-through resistance, or the possible flammability implications of explosion resistant cargo containers.

The following is a table of all of the issues for research that were raised during the breakout session, and the actual voting for each of the items. The items are ordered according to the total number of "High" priority votes they received, although the numbers are not scientifically generated and reflect only the views of the people present for the breakout session.

A more detailed summary of each item is included on the following page.

Subject	High	Medium	Low	"NO"
Burn-Through	31	4	0	0
Improved Interior Materials	25	10	2	0
Hidden Fires	24	11	0	0
Oxygen Systems	21	14	0	0
Portable Extinguishers.	17	9	8	0
Electrical Systems	16	16	1	1
Corrosion Inhibitors	10	17	6	3
Improved Smoke Detectors	10	16	9	1
Cabin Waterspray	10	9	24	2
Wear/Damage to materials	5	13	13	2
Carry-on Baggage	5	12	12	6
Toxicity/Corrosivity Tests	4	14	11	3
Intumescent Coatings	3	8	22	3
Smoke Hoods	2	8	15	10
Hazardous Goods	2	5	19	9
Flight Attendant Uniforms	0	3	23	9
Transparencies	0	3	13	14

This ranking of items does not include a consideration of whether an item was a "long term" or "short term", and whether the payoff from the research would or could be rulemaking. In addition, many items have several components that would have to be considered in order to address the item.

1. Burn-Through: The issue of factors relating to burn-through performance, including such things as insulation blankets that are not part of the fuselage.

2. Improved Interior Materials: Generally, research into materials that have improved fire safety characteristics over those in use today.

3. Hidden Fires: All aspects of hidden fires including design, materials, maintenance and their interaction.

4. Oxygen Systems: Consideration of oxygen systems fire safety as well as looking at the role of the oxygen and whether the benefit outweighs the risk, or could be implemented differently.

5. Portable Extinguishers: Development of new test methods to provide certification criteria for any new agents that are developed to replace halon.

6. Electrical Systems: General research into improved electrical system fire safety.

7. Corrosion Inhibitors: The effect of corrosion inhibitors that are now being used on burn-through characteristics.

8. Improved Smoke Detectors: Primarily smoke detectors for lavatories, primarily to detect smokers. Such research would undoubtedly have applicability to other uses, such as cargo compartments.

9. Cabin Waterspray: Further consideration of waterspray for the cabin, although it would probably apply as other applications as well.

10. Wear/Damage to materials: The effect of wear and damage to material flammability

11. Carry-on Baggage: Assessment of the impact of carry-on baggage on a fire, and possible methods to deal with it (if the impact is significant.)

12. Toxicity/Corrosivity Tests: Research directed toward toxicity standards, and the effect burning materials products of combustion on metallic materials corrosivity

13. Intumescent Coatings: General research toward wide usage of intumescent coatings

14. Smoke Hoods: Research into means to provide protection to passengers i n the presence of toxic gases, and a new, empirical assessment of smoke hoods benefits and detriments.

15. Hazardous Goods: The impact of hazardous goods that are unlabeled on fire safety.

16. Flight Attendant Uniforms: Need for, and possible standards for flight attendant uniforms. Materials and styles.

17. Transparencies: Research into better materials for transparent or translucent parts used in the cabin, which are currently excluded from the heat release rule.

Gardlin/Sarkos

INTERNATIONAL CONFERENCE ON CABIN SAFETY RESEARCH
ATLANTIC CITY
NOVEMBER 14-16, 1995

REPORT OF THE IN-FLIGHT EMERGENCIES BREAKOUT SESSION

Breakout Session Chaired by:

Nicholas J Butcher - United Kingdom Civil Aviation Authority
Nora C Marshall - United States National Transportation Safety Board

REVIEW OF OUTSTANDING QUESTIONS FROM PRESENTATIONS

In-flight Cabin Emergencies Reported to ASRS (Aviation Safety Reporting System)

In response to a question about availability of ASRS forms it was stated that they were available from NASA Ames at the following address:

Linda J Connell, M.A.
NASA Ames Research Centre
Mail Stop 262-1
Moffett Field
California, 94035-1000
USA

Phone: (415) 969 - 3969 Fax: (415) 967 - 4170

Data Collection Regarding In-flight Emergencies

It was stated that the purpose of the British Airways BASIS system was not to identify areas for research. The BASIS system was primarily used to identify and track potential problem areas so that appropriate action could be taken by the operator at an early stage.

In-flight Medical Emergencies

In response to a question regarding flight attendant training the presenter was of the opinion that the requirements needed to be reviewed.

It was stated that during in-flight medical emergencies, specialist medical advice on the ground should be sought in order to address the specific medical condition.

It was also stated that Doctors who identify themselves on a flight may be specialists in one particular field but not fully conversant with the specific procedures that should be applied to the particular medical emergency being encountered. Doctors were reluctant to identify themselves on a flight because of possible litigation if the outcome of the situation was not successful.

In response to a question it was stated that there was no record of the number of medical emergencies where trained medical personnel (eg doctors or nurses) had assisted during the flight. The decision to divert rested with the aircraft commander who would take into

account all available advice. Diversion factors that an aircraft commander should take into account include routing, weather, sector duration and available medical facilities at diversion points. In a well organised airline operation all these factors are taken into consideration and many operators have computerised systems to assist aircraft commanders.

Passenger Brace Position for Impact

In response to a question regarding availability of the research report, it was stated that this work had been published in **CAA Paper 95004 "A Study of Aircraft Passenger Brace Position for Impact"**. The report was available from:

CAA Printing and Publications
Greville House
37 Gratton Road
Cheltenham
GloucestershireGL50 2BN.
United Kingdom

DISCUSSION ON THE NEEDS FOR FUTURE RESEARCH

The Chairpersons outlined the purpose of the breakout session and the need to present the main conclusions during the concluding session. The Group was advised that this was their opportunity to identify areas where they considered that research was required. The purpose of the session was to identify areas of cabin safety research and not to debate the problems with the application of current requirements.

The following is a summary of the discussions that took place during the breakout session.

1. MEDICAL REQUIREMENTS

Research Priority: HIGH

1.1 **First Aid Kits and Doctors Kits:** The Group was of the opinion that a review of in-flight medical emergencies was required in order to determine the different types of medical cases encountered. This would also identify the drugs and equipment needed to deal effectively with specific problems.

1.2 **Flight Attendant Training:** The Group considered that the above review would also assist in determining the required level of flight attendant first aid training and the first aid subjects that should be given priority.

1.3 **Causes of Diversions:** It was felt that the review should also look at the numbers and causes of diversions. This should take into account passenger age, recent illness or surgery, relation of ADA Enactment (Americans with Disabilities), distress, psychiatric problems, etc.

2. PASSENGER BRACE POSITION FOR IMPACT

Research Priority: HIGH

2.1 **Short Notice Advice to Passengers:** The Group identified that many operators have different commands for the short notice emergency. These include commands such as "***Brace Brace***", "***Heads down***" and "***Grab ankles***". However, in this type of emergency scenario it is not known which command affords the seated occupant the best protection from impact injuries. The Group were of the opinion that research should be undertaken to identify the "short notice" commands which would achieve the best brace position for passenger protection.

2.2 **Flight Attendant Brace Position for Impact:** The Group recognised that whilst there had been considerable effort made in the United Kingdom to address the best brace position for passengers, no such work had recently been conducted for flight attendants. It was thought that the FAA might have conducted work several years ago on which they based some recommended guidance to US operators (**Air Carrier Operations Bulletin No. 1-16-23 "Brace for Impact Positions"**). The Group recommended that work be undertaken to look at flight attendant brace position for forward and aft facing seat orientations.

2.3 **Passenger Brace Position for Impact:** The Group recognised the importance of the work that had been conducted in the United Kingdom on the passenger brace position (**CAA Paper 95004 "A Study of Aircraft Passenger Brace Position for Impact"**). However, concern was expressed that to date this work had not necessarily been accepted internationally and the Group considered it necessary for the Regulatory Authorities to reach a harmonised position.

3. PASSENGER EDUCATION

Research Priority: HIGH

3.1 **Effectiveness of Passenger Safety Briefings:** The Group discussed the continuing problems of the effectiveness of the pre-flight safety briefing to passengers and the levels of passenger attention to the briefing. The Group was of the opinion that a review should be conducted into the order of the briefing and the importance of the briefing items (ie should exit location take priority over lifejacket location and operation). Such a review should also identify which subjects passengers find easy to understand and which items they find difficult.

3.2 **Retention of Information:** The Group also discussed the problems of passenger retention of safety information. Research had been conducted some years ago in the United Kingdom (**CAA Paper 92015 "Passenger Attitudes Towards Airline Safety Information and Comprehension of Safety and Briefing Cards"**). The Group considered that this research should now be expanded to include the aspects specified in 3.1 and include the potential problems of information retention. For example, after a fourteen hour sector, there might be a need to repeat safety information to passengers on such items as exit location, floor proximity lighting systems, seat belt operation, etc.

3.3 **Video Briefing Versus Practical Demonstration:** The Group also felt that there was a need to conduct research into the effectiveness of video briefing compared to the effectiveness of

practical demonstration. The Group was also concerned at the duration of passenger briefings and considered it important to know the optimum duration of a video briefing compared to the optimum duration of a practical demonstration.

3.4 **International Standardisation of Safety Information:** There was a brief discussion on the merits of standardisation of safety information. Many of the Group considered that there was merit in having a set standard of safety information but were of the opinion that operators should be allowed to maintain an individual approach to the way in which this information is presented.

Note: The National Transportation Safety Board published a Safety Study in 1985, "**Airline Passenger Safety Education: A Review of Methods Used to Present Safety Information**".

4. PASSENGER BEHAVIOUR

4.1 **Incidents of Passenger Assault and Disturbances:** The Group was concerned at the increasing trend involving passenger disturbances and incidents of assaults by passengers. The Group was of the opinion that research was needed of world-wide incidents in order to determine the following:

a. the nature of the incident,

b. the potential affects on flight safety; and

c. the financial implications of diversion costs (to off-load offending passenger).

The Group also discussed the problems encountered with local authorities on arrival in different countries and the difficulties in taking appropriate legal action against individual offenders. It was thought this matter had been subject of discussion at a recent IATA Conference.

4.2 **Passenger Restraint Kits:** The above research might determine if there is a need to mandate operators to carry restraint kits. Restraint kits are currently carried by several operators as non-mandatory equipment.

5. CABIN ENVIRONMENT

Research Priority: HIGH

The problems of air quality and cosmic radiation were discussed by the Group. It was felt that there must already have been much research undertaken on these subjects and that a literature review would identify if further research is required.

6. TURBULENCE

Research Priority: MEDIUM

6.1 **Prediction and Avoidance:** The Group considered that in minimising the risk of in-flight turbulence the emphasis should be placed on prediction and avoidance. As with the previous

subject it was felt that there must be considerable information already available on this subject and that a literature review might identify if further research is required.

6.2 **Effectiveness of Seat Belt Signs:** The Group discussed the effectiveness of seat belt signs and came to the conclusion that research should be undertaken into the effectiveness of current seat belt signage. Many aircraft have illuminated signs that show when seat belts should be fastened but does not show how the belt is fastened. The sign is turned off during the cruise but passengers are often advised to keep their seat belt on during flight. Some airlines keep the seat belt sign on during the cruise but allow the passengers to move around the cabin (eg. visits to restrooms). The Group felt that all this must be extremely confusing to passengers and that the entire subject was worthy of a research project.

6.3 **De-lethalisation of Cabin Fittings and Equipment:** The need to de-lethalise cabin areas was discussed by the Group. Also discussed was the introduction of new cabin fittings such as passenger in-flight entertainment equipment which may significantly increase the potential for passenger injury during clear air turbulence. The MD-11 inadvertent slat deployment was also mentioned as an example of how in some emergency scenarios the potential for injury can be extremely high and can in the worst cases lead to fatalities. The Group also discussed the introduction of new concepts such as coffee bar installations and the increased potential for injury to passengers. It was agreed that Regulatory Authorities needed to consider the implications of such new concepts and how these should be addressed by new certification and operational requirements.

6.4 **Service Conflicts and Flight Attendant Injury:** The Group discussed the need for an in-depth review of operators procedures for the continuance of passenger service during turbulence. A review of injuries to flight attendants might identify if such injuries are directly linked to continued service at times of turbulence, descent, etc.

Note: The FAA's Associate Administrator for Aviation Safety, sponsored an Industry/Government Cabin Safety Roundtable on Reduction of Turbulence Related Injuries. The FAA Office of Integrated Safety Analysis published Proceedings. For more information contact:

Mr Peter McHugh
Federal Aviation Administration
ASY-200
400 7th Street S.W.
Room 2228
Washington, D.C. 20590
USA

7. IN-FLIGHT FIRE

Research Priority: LOW

7.1 **Flight Attendants Uniform:** This was briefly discussed by the Group who considered that there was some merit for conducting research into flammability standards. This subject was also discussed by the Fire Safety Breakout Session Group who rated this research subject as low priority. They were divided between those who thought that flammability standards should be developed, and others who said that appropriate materials are already available.

7.2 **Scale and Scope of Fire Fighting Equipment:** It was agreed that flight attendant fire and smoke training should be enhanced in respect of hidden fires. It was suggested that some of the possible halon replacements being looked at were not as easy to use as halon 1211 and that this may have significant implications for future training. The Group identified that not all Regulatory Authorities required the carriage of fire axes, or fire gloves, and that some Regulatory Authorities had not yet introduced requirements for Protective Breathing Equipment (PBE). It was agreed by the Group that in recent years the only in-flight fire incident where the scale and scope of fire fighting equipment was called into question involved a Boeing 747 combi aircraft in 1987.

8. DECOMPRESSION

Research Priority: LOW

The Group was of the opinion that research could be conducted on the time of useful consciousness, especially for aircraft flying at higher altitudes.

9. CREW CO-ORDINATION AND COMMUNICATION

Research Priority LOW

The Group discussed the problems of flight crew and flight attendant co-ordination and communication and the need for CRM training for flight attendants as well as flight deck crew. It was considered that much had been achieved in respect of CRM and that in both North America and in Europe new requirements and recommendations would greatly enhance the "total crew" concept.

10. FLIGHT ATTENDANT RATIO TO PASSENGERS

Research Priority: LOW

The Group was of the opinion that the current 1 flight attendant to 50 passengers rule was too simplistic and that other factors need to be taken into consideration. The Group considered that research should be conducted to look into a variety of emergency scenarios where perhaps additional flight attendants might increase the chances of a successful outcome in an emergency. The research should also consider the effectiveness of emergency drills, the number and types of exits, the cabin configuration such as dual aisle and single aisle aeroplanes, ETOPs equipment and procedures, etc.

LIST OF ATTENDEES

LIST OF ATTENDEES

Mr. Erik Aaserud
SAS-Scandinavian System
Technical Division
Maintenance Base-Oslo
N-1330 Oslo
Norway
Phone: 47 67 59 66 96
Fax: 47 67 59 69 62

Mr. Herman Ada
Continental Micronesia
PO Box 8778
Tamuning GU 96911
Phone: 671-646-9586
Fax: 671-649-5220

Ms. Angela Adair
American Eagle
PO Box 619616
MD 5494
DFW Airport TX 75261
Phone: 817-967-8051
Fax:

Gerri Adams
United Airlines
7401 Martin Luther King Blvd.
Denver CO 80207
Phone: 303-780-5575
Fax: 303-780-5631

Mr. Hala Akkad
Saudia Airlines
PO Box 167, ci 959
Jeddah 21231
Saudi Arabia
Phone: 2 682 9700 X3094
Fax: 2 686 1988

Mr. John Amoretti
FAA Tech Ctr.
AAR-431/Bldg. 201
Aircraft Struct. Crashworthiness
Atlantic City International Airport NJ 08405
Phone: 609-485-6135
Fax: 609-485-4004

Mr. Thomas Anderson
BF Goodrich Aircraft
3414 S. Fifth Street
Phoenix AZ 85040
Phone: 602-232-4012
Fax: 602-232-4100

Mr. Dave Anderson
M.C. Gill Corp.
4056 Easy Street
El Monte CA 91731-1087
Phone: 818-443-6094 Ext. 2213
Fax: 818-350-5880

Mr. Leif Anderson
SAS Flight Academy
Amagerstrandvej 390
DK-2770 Kastrup
Denmark
Phone: 4532325335
Fax: 4532325991

Mr. Tracy Angles
Airline Diviof CUPE
180 Attwell Drive
Suite 600
Etobicoke Ontario M9W 6A9
Canada
Phone: 416-798-3399
Fax: 416-798-3411

Mr. Dale Atkinson
DBA Consulting
7703 Carrleigh Parkway
Springfield VA 22152
Phone: 703-451-3011
Fax: 703-451-4278

Ms. Doris Au
Hong Kong Dragon Air
22/T Devon House
Taikoo Place/979 King's Road
Quarry Bay
Hong Kong
Phone: 852 2590 1471
Fax: 852 2590 1333

Mr. Charles Barresi
SMR Technologies, Inc.
PO Box 326
1420 Wolf Creek Trail
Sharon Center OH 44274
Phone: 216-239-1000
Fax: 216-239-1352

Mr. Cliff Barrow
U.K.Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone:
Fax: 44 1 293 573 975

Mr. Thomas Barth
Simula, Inc.
10016 South 51st Street
Phoenix AZ 85044-5299
Phone: 602-730-4185
Fax: 602-893-8643

Ms. Linda Beckett
Scisafe
274 Ecclesall Road South
Sheffield S11 9PS
England
Phone: 11 4 235 1 405
Fax: 11 4 235 1 405

Mr. William Beckett
Scisafe
274 Ecclesall Road South
Sheffield S11 9PS
England
Phone: 11 4 235 1 405
Fax: 11 4 235 1 405

Mr. Hanns-Jorg Betz
Lufthansa Technik
Dept. FRAWF22 Airport Area West
D60546 Frankfurt
Germany
Phone: 49 69 696 4612
Fax: 49 69 696 4617

Mr. Dave Blake
FAA Technical Center
Fire Safety Section
Building 275, AAR-422
Atlantic City International Airport NJ 08405
Phone: 609-485-4525
Fax: 609-485-5580

Mr. Jay Herman Blum
Craftex Mills, Inc.
PO Box 3017
450 Sentry Parkway E.
Blue Bell PA 19422-0795
Phone: 215-941-1212
Fax: 215-941-7171

Mr. Jon Boley
Simmons Air/Amer. Eagle
2955 Alouette Drive
Apt. 912
Grand Prairie TX 75052
Phone: 214-602-3042
Fax:

Ms. Ulla Bolter
ITF
Box 30102
104 25
Stockholm
Sweden
Phone: 46 8 737 800
Fax: 46 8 618 2245

Mr. Joseph Botelho
Albany Int'l Research Co.
777 West Street
PO Box 9114
Mansfield MA 02048
Phone: 508-339-7300
Fax: 508-339-4996

Captain Peter Boulding
British Airline Pilots Assoc.
44, Badingham Drive
Fetcham
Surrey KT22 9HA
England
Phone: 44 1372 374 099
Fax: 44 1372 363958

Ms. Debbie Boyle
CUPE Airline Division
55 Oakmount Road
Apt. 1704
Toronto Ontario M6P 2M5
Canada
Phone: 416-762-1091
Fax: 416-798-3411

Mr. Mike Brookman
DME Corporation
111 S.W. 33rd Street
Ft. Lauderdale FL 33315
Phone: 305-975-2162
Fax: 305-979-3313

Mr. Sabine Buhrig
Metzeler Sohaum GmbH
87700 Memminger
Donaustr. 51
Germany
Phone: 49 8331 830 284
Fax: 49 8331 830 279

Ms. Jayne Bullock-Plumb
Macrsk Air Ltd.
22452249 Coventry Road
Birmingham B26 3NG
England
Phone: 44 121 743 9090
Fax: 44 121 743 4123

Mr. Nick Butcher
U.K.Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone:
Fax: 44 1 293 573 991

Mr. Scott Campbell
McDonnell Douglas
3855 Lakewood Boulevard
Dept. KD3 Mail Code: 801-38
Long Beach CA 90846
Phone: 310-593-4975
Fax: 310-593-5605

Mr. Don Cardis
Schneller, Inc.
Box 670
6019 Powder Mill Road
Kent OH 44240
Phone: 216-673-1400
Fax: 216-673-6374

Mr. Kevin Carmen
Galaxy Scientific Corp.
c/o FAA Technical Center
AAR-422/Bldg. 275
Atlantic City International Airport NJ 08450
Phone: 609-485-4526
Fax: 609-485-5580

Mr. Bruno Carriere
Aerospatiale
316 Route de Bayonne
31060 Toulouse Cedex 03
France
Phone: 33 61 18 09 06
Fax: 33 61 18 04 95

Mr. Richard Chan

13110 Saticoy Street
Unit C
North Hollywood CA 91605
Phone: 818-982-7327
Fax: 818-982-0122

Mr. Richard Chandler

1425 Beverly Hills
Norman OK 73072
Phone: 405-364-4145
Fax:

Mr. Claude Charland
Transport Canada
Place de Ville, Tower C
4th Floor, Area B, 330 Sparks Street
Ottawa Ontario K1A ON8
Canada
Phone: 613-990-1052
Fax: 613-954-1602

Dr. C.S. Chen
Ctr for Aviation & Space Tech.
Bldg. 12
321 Kuang Fu Rd/Section 2
Hsinchu 00300
Taiwan
Phone: 886 35 732287
Fax: 886 35 727 322

Mr. Ray Cherry
R.G.W. Cherry & Assoc.
75, Moorlands
Welwyn Garden City
Herts AL7 4QJ
England
Phone: 44 1707373767
Fax: 44 1707 392129

Mr. Brad Christensen
C&D Interiors
5412 Argosy Drive
Huntington Beach CA 92649
Phone: 714-891-1906
Fax: 714-895-6884

Ms. Lydia Chuan-hui LIU
Great China Airlines
Sung-Shon Airport, Taipei
260 Pa-teh Road, Section 2,
Taipei Taiwan
People's Republic of China
Phone: 886 2 545 1841
Fax: 886 2 718 7684

Mr. Newton Chung Tak ZAH
Cathay Pacific Airways
85 Concorde Road
FOP-Safety Training School
Hong Kong International Airport
Hong Kong
Phone: 852 2747 1765
Fax: 852 2320 4162

Mr. Rick Closson
Douglas Aircraft
PO Box 1771
Mail Stop: 35-35
Long Beach CA 90801
Phone: 310-593-6512
Fax: 310-593-8302

Mr. Don Collier
Air Transport Assoc.
1301 Pennsylvania Avenue, NW
Washington DC 20004-1707
Phone: 202-626-4017
Fax: 202-626-4081

Mr. Kirke Comstock
United Airlines
San Francisco Int'l Airport - SFO EG
Maint. Operations Center
San Francisco CA 94128
Phone: 415-634-7015
Fax: 415-634-7070

Mr. Eual Conditt
FAA Wichita-ACO
1801 Airport Road, Room 100
Midcontinents Airport
Wichita KS 67209
Phone: 316-946-4128
Fax: 316-946-4407

Mr. Joseph Condon
Boeing
PO Box 3707 M/S OR-LA
Seattle WA 98124-1125
Phone: 206-342-7966
Fax: 206-342-0914

Ms. Marie-Anyk Cote
Inter-Canadien
795 boulevard Stuart-Graham North
Dorval Quebec H9R 4N9
Canada
Phone: 514-631-9802
Fax: 514-631-0767

Mr. Donald Crane
Calspan SRL Corp.
4455 Genesee Street
PO Box 400
Buffalo NY 14225
Phone: 716-631-6854
Fax: 716-631-6845

Ms. Brenda Crockett
Kiwi Int'l Air Lines, Inc.
Hemisphere Center
U.S. 1&9 South
Newark NJ 07114
Phone: 305-874-6727
Fax: 201-645-1161

Mr. Herb Curry
Herb Curry, Inc.
Burn Lab, Bldg. 30
One Lexan Lane
Mt. Vernon IN 47620
Phone: 812-831-7769
Fax: 812-831-7252

Ms. Collette D'Arcy
Phoenix Fire Inhibitor Ltd.
North Road Industrial Estate
Ellesmere Port
Cheshire L6S 1AB
England
Phone: 44 151 356 4900
Fax: 44 151 356 1300

Ms. Mika Dahlberg
Finnair
Finnair E1/30
Finnair 01053
Finland
Phone: 358 818 6431
Fax: 35 8 81 86 732

Ms. Angela Dahlberg
Dahlberg & Associates
1107 Lake Sylvan Drive, S.E.
Calgary
Alta, T2J 2P9
Canada
Phone: 403-271-2901
Fax: 403-278-6036

Mr. Guy Dalla Riva

378 Fowling Street
Playa Del Rey CA 90293
Phone: 310-821-7779
Fax:

Mr. George Danker
Akro Fireguard Products
9001 Rosehill Road
Lenexa KS 66215
Phone: 913-888-7172
Fax: 913-888-7372

Mr. James Davis
Accufleet
363 N. Sam Houston Pkwy #1460
Houston TX 77060
Phone: 713-999-8800
Fax: 713-999-9066

Ms. Ethel Dawson
Accufleet
363 N Sam Houston Pkwy E#1460
Houston TX 77060
Phone: 713-999-8800
Fax: 713-999-9066

Mr. Luiz Sergio De Almeida Dias
Sindicato Nac'l Dos Aero.
Rua Marechal Camara
160/1620-Ed. Orly
Rio de Janeiro, RJ CEP20020-080
Brasil
Phone: 55 21 532 1163
Fax: 55 21 220 6693

Mr. Giovanni De Pauli
Lufthansa German Airlines
Lufthansa-Rasis
FRA CF
60546 Frankfurt
Germany
Phone: 49 69 696 3066
Fax: 49 69 696 8600

Mr. Stephane Deharvengt
DGAC & SPACT/R
48 Rue Desmoulins
Issy Les Moulineaux 92452
France
Phone: 33 1 41 09 46 87
Fax: 33 1 41 09 45 13

Mr. Charles A. DeJohn
Federal Aviation Administration
AAM-610
PO Box 25082
Oklahoma City OK 73125
Phone: 405-954-5519
Fax: 405-954-1010

Mr. Jean-Paul Deneuville
STPA/N Airworthiness Dept.
4 Avenue de la Porte d'Issy
75015 Paris
France
Phone:
Fax: 33 1 4552 4301

Mr. Robert Denkmann
Boeing Commercial Airplane Group
Phone:
Fax:

Ms Francine Desjardins Lafond
Air Transat
11,600 Cargo Road A 1
Aeroport International de Montreal
Mirabel Quebec J7N 1G9
Canada
Phone: 514-476-1011
Fax: 514-476-0338

Ms. Mona Desrosiers
Transport Canada
700 Leigh Capreol
Dorval Quebec H4Y 1G7
Canada
Phone: 418-640-2748
Fax: 418-640-2749

Mr. Jean-Francois Detienne
DGAC - France
48 rue Camille des Moulins
92452 Issy les Moulineaux
France
Phone: 33 1 41 09 48 32
Fax: 33 1 41 09 45 13

Mr. Dung Do
FAA Technical Center
Fire Safety Section
AAR-422/Bldg. 275
Atlantic City International Airport NJ 08405
Phone: 609-485-4328
Fax: 609-485-5580

Mr. Darren Dodd
Faverdale Engineering Group
Faverdale Industrial Estate
Darlington Co. Durham DL3 0QL
England
Phone: 44 1 325 381220
Fax: 44 1 325 381218

Ms. V.M. (Marie) Doll
Transport Canada Aviation
Int'l Harmnztn. Regltns.
Narono Bldg/360 Laurier Ave/6th Fl./Area D
Ottawa Ontario K1A 0N8
Canada
Phone: 613-991-4745
Fax: 613-991-4746

Mr. Ronald Downs
British Airways
Compass Centre (5709)
Heathrow Airport
Hounslow TW6 2JA
England
Phone: 44 181 513 0030
Fax: 44 181 513 0069

Mr. Larry Dvorak
Raytheon Aircraft Co.
P.O. Box 85
Wichita KS 67206
Phone: 316-676-8991
Fax: 316-676-7440

Dr. Thor Eklund
FAA Technical Center
Building 204/AAR-423
Fire Research Section
Atlantic City International Airport NJ 08405
Phone: 609-485-5532
Fax: 609-485-5785

Ms. Jeanne Elliott
Northwest Airlines
16215 S.E. 31st Street
Bellevue WA 98008
Phone: 206-747-6475
Fax:

Mr. David M. Elliott
Stanley Works
16215 S.E. 31st Street
Bellevue WA 98008
Phone: 206-747-6475
Fax:

Mr. Claudio Eminente
Registro Aero. Italiano
Italian Airworthiness Authority
Via Del Tritone, 169
Rome 00187
Italy
Phone: 39 6 67584207-8
Fax: 39 6 69941468

Mr. Soren Ewaldsson
Saab Aircraft AB
Airworthiness
S-58188 Linkoping
Sweden
Phone: 46 13 184704
Fax: 46 13 181700

Mr. W.H. "Skip" Face
HSH Interplan-USA Inc.
17451-G. Mt. Herrmann Street
Fountain Valley CA 92708
Phone: 714-444-1549
Fax: 714-444-1649

Dr. Mario Farioli
Ctr of Italian Aerospace Res.
Via Maiocise
81043 Capua
Italy
Phone: 39 823 623 110
Fax: 39 823 623 126

Mr. John Farrell
Albany Int'l Research Co.
777 West Street
PO Box 9114
Mansfield MA 02048
Phone: 508-337-9544
Fax: 508-339-4946

Mr. Jim Federer
Southwest Airlines
Training Center
2700 Love Field Drive
Dallas TX 75019
Phone: 214-904-5272
Fax: 214-904-5219

Mr. Reinhard Felder
Schneller, Inc.
6019 Powdermill Road
PO Box 670
Kent OH 44240
Phone: 216-673-1400
Fax: 216-673-7327

Mr. Ray Fenster
Assoc. of Flight Attendants
1625 Massachusetts Ave NW/3rd Floor
Washington DC 20036
Phone: 202-328-5400
Fax:

Mr. Peter Fiala
Aim Aviation, Inc.
705 S.W. 7th Street
PO Box 9011
Renton WA 98057
Phone: 206-235-2750
Fax: 206-228-0761

Mr. Bob Filipczak
FAA Technical Center
AAR-422/Building 277
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-4529
Fax: 609-646-5229

Mr. Vittorio Fiorini
RAI
Via del Tritone 169
Roma 00187
Italy
Phone: 39 6 678 3696
Fax: 39 6 678 1318

Mr. Ron Fisher
Defense Fire Protection
PO Box 1310
Falls Church VA 22041
Phone: 703-379-6382
Fax: 703-379-9256

Mr. Larry Fitzgerald
FAA Technical Center
Building 287/AAR-422
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-5852
Fax: 609-646-5229

Ms. Colleen Ford
Execujet Services, Inc.
1020 N. Milwaukee Avenue
Suite 300
Deerfield IL 60015
Phone: 713-520-7156
Fax: 713-520-7156

Ms. Karen Forest
FAA - ACO
2300 E. Devon Avenue
Des Plaines IL 60018
Phone: 708-294-7697
Fax: 708-294-7834

Dr. Herman Forsten
Dupont
E.I. Du Pont de Nemours and Company
Chestnut Run Plaza-Oak Run/Bldg 715
Wilmington DE 19880-0701
Phone: 302-999-2697
Fax: 302-999-2718

Ms. Vickie Foster
American Eagle
PO Box 619616
MO 5494
DFW Airport TX 75261
Phone: 817-967-8367
Fax:

Mr. C.L. Foushee
Albany Int'l Research Co.
1814 138th Place S.E.
Bellevue WA 98005
Phone: 206-746-8111
Fax: 206-641-8844

Ms. Geraldine Frankoski
Aviation Consumer Action
PO Box 19029
Washington DC 20036
Phone: 202-638-4000
Fax: 202-638-0746

Mr. Gary Frings
FAA Technical Center
AAR-431/Building 201A
Aircraft Structural Crashworthiness
Atlantic City International Airport NJ 08405
Phone: 609-485-5781
Fax: 609-485-4004

Mr. Kevin Fryer
Cessna Aircraft Co.
Department 009C
Three Cessna Blvd.
Wichita KS 67215-1400
Phone: 316-941-7268
Fax: 316-941-7925

Mr. Ed Galea
University of Greenwich
Woolwich Campus
Numerical Modelling Ctr/Wellington St
Woolwich London SE18 6PF
England
Phone: 44 181 331 8730
Fax: 44 181 331 8665

Mr. Uday Garadi
FAA -Southwest Region
Rotorcraft Certification Office
ASW-170
Fort Worth TX 76193-0170
Phone: 817-222-5157
Fax: 817-222-5960

Mr. Jeff Gardlin
FAA Aircraft Cert. Div.
1601 Lind Avenue, SW
ANM-114
Renton WA 98055-4056
Phone: 206-227-2136
Fax: 206-227-1100

Ms. Mary Lynn Gardner
Kiwi Int'l Air Lines, Inc.
Hemisphere Center
U.S. 1&9 South
Newark NJ 07114
Phone: 305-874-6727
Fax: 201-645-1161

Mr. James Garman
Sikorsky Aircraft Corp.
Mail Stop: B101A
6900 Main Street, PO Box 9729
Stratford CT 06497-9129
Phone: 203-384-7195
Fax: 203-384-6701

Professor Hae Chang Gea
Rutgers University
Dept. of Mechanical & Aerospace Engnrg.
Piscataway NJ 08855-0909
Phone: 908-445-0108
Fax: 908-445-5313

Mr. David Genovese
SMR Technologies
PO Box 326
Sharon Center OH 44274
Phone: 216-239-1000
Fax: 216-239-1352

Professor Vittorio Giavotto
Ctr of Italian Aerospace Res.
Via Maiocise
81043 Capua
Italy
Phone: 39 823 623 110
Fax: 39 823 623 126

Mr. Gillereau
Aerospatiale-Avions
316 route de Bayonne
31060 Toulouse Cedex 03
France
Phone: 33 61 93 55 50
Fax: 33 61 18 29 34

Mr. _Marc Goldstein
FAA - ACO
10 Fifth Street
Third Floor
Valley Stream NY 11581-1200
Phone: 516-256-7513
Fax: 516-568-2716

Mr. Richard Gooch
Trans World Airlines
Rm 1-446
KCI A/P
Kansas City MO 64195
Phone: 816-891-4889
Fax: 816-891-1999

Billie Good
Simmons Airlines
614 N.W. 14th Street
Assoc. of Flight Attendants
Oklahoma City OK 73103
Phone: 405-524-3572
Fax: 405-954-3705

Mr. Mike Gordon
Cabin Crew 89
81 New Road, Harlington
Hayes
Middlesex UB3 5BG
England
Phone: 44 181 759 5836
Fax: 44 181 759 6077

Mr. James Gourley
Amtrak
30 th Street Station
4th Floor South
Philadelphia PA 19104
Phone: 215-349-2786
Fax: 215-349-2767

Lt. Wayne Graves
Dept. of National Defence
Air Command Headquarters
Westwin
Manitoba R3J OTO
Canada
Phone: 204-833-5229
Fax: 204-833-5492

Mr. Graham Greene
U.K. Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone: 44 1 293 573 462
Fax: 44 1 293 573 981

Mr. Buddy Guess
Delta Airlines
PO Box 20706
Atlanta GA 30320-6001
Phone: 404-714-2411
Fax: 404-714-3304

Ms. Yuying Guo
Shanghai Aircraft Research Inst.
/Longhua Airport Bldg
PO Box 232-003/Mat'ls Stnds. Dept.
Shanghai _200232
People's Republic of China
Phone: 21 64388606
Fax: 21 6439 0584

Ms. Deborah Hamby
Delta Airlines Inc.
Dept 967
1021 N. Loop Road
Atlanta GA 30320-9998
Phone: 404-715-0953
Fax:

Mr. Gary Graham
Ind. Fed. of Flight Attendants
720 Olive Street
Suite 1700
St. Louis MO 63101
Phone: 314-621-1177
Fax: 314-621-3722

Ms. Cynthia Gray
MedAire, Inc.
1301 E. McDowell Road
Suite 101
Phoenix AZ 85006
Phone: 602-263-7971
Fax: 602-252-8404

Mr. Roland Don Griot
KLM Flight Tech. Dept.-Flight Safety
/PO Box 7700
Bldg. 404/Mail Code: SPL/OD-EEP
1117ZL Schiphol Airport
The Netherlands
Phone: 31 20 6499739
Fax: 31 20 6499772

Mr. Zhongyu Guo
CAAC
155 Dongsi Street West
Office of Aviation Safety/Air Safety Office
Beijing I00710
China
Phone: 86 10 403 6373
Fax: 86 10 4013829

Mr. Shingo Hagihara
Showa Aircraft Industry Co.
8227 44th Avenue, NW
Suite AF
Mukiteo WA 98075
Phone: 206-290-7399
Fax: 206-355-9075

Ms. Shannon Hardy
American Airlines
4333 Amon Carter Boulevard
Mail Drop 5425
Ft. Worth TX 76155
Phone: 817-967-9002
Fax: 817-967-9352

Mr. Jeffrey Hare
J. Hare Safety/Survival
PO Box 300528
JFK Airport Station
Jamaica NY 11430-0528
Phone: 718-457-3579
Fax: 718-457-3579

Mr. Sham Hariram
McDonnell Douglas
3855 Lakewood Blvd.
M/C: 800-32
Long Beach CA 90846
Phone: 310-593-4305
Fax: 310-593-7104

Mr. Jack Hart
Heath Tecna Aerospace
19819 84th Avenue South
Kent WA 98032
Phone: 206-872-7500 Ext. 4289
Fax: 206-375-1237

Ms. Susan Hart
Air Alliance
611, 6th Avenue
Aeroport de Quebec Ste-Foy
Que G2E 5W1
Canada
Phone: 418-872-7622
Fax: 418-872-9716

Ms. Sally Hasselbrack
Boeing
PO Box 3707
MS: OR-MM
Seattle WA 98124
Phone: 206-342-9947
Fax: 206-717-0460

Ms. Donna Heinlein
USAir, Inc.
Parkridge II
15 Commerce Drive
Pittsburgh PA 15275
Phone: 412-747-3871
Fax: 412-747-3051

Mr. Ulrich Heitmann
Metzeler Sohaum GmbH
87700 Memminger
Donaustr. 51
Germany
Phone: 49 8331 830 437
Fax: 49 8331 830 272

Mr. Hans Helsdingen
HSH Aerospace Finishes
Hendrik Drapsstraat 6B
1853 Strohbeek-Bever
Belgium
Phone: 32 2 2672670
Fax: 32 2 267 4934

Mr. Robert Herman
Advocacy Attorney
Paralyzed Veterans of America
801 Eighteenth Street, NW
Washington DC 20006
Phone:
Fax:

Mr. Carlos Hilado

PO Box 13080
Sissonville WV 25360
Phone: 304-984-2994
Fax:

Mr. Richard Hill
FAA Technical Center
Building 287/AAR-422
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-5997
Fax: 609-646-5229

Mr. Ueda Hirohisa
Japan Airlines
West Passenger Terminal 3-2
Haneda Airport 3 chome Ota-Ka
Tokyo 144
Japan
Phone: 03-5756-3164
Fax: 03-5756-3529

Ms. Peggy Holcomb
Southern Mills
PO Box 289
6501 Mall Blvd.
Union City GA 30291
Phone: 770-969-1000
Fax: 770-969-6846

Mr. Richard Honigsbaum

A-21 Barry Gardens
245 Passaic Avenue
Passaic NJ 07055
Phone: 201-473-0735
Fax: 201-779-6775

Ms. Terri Hopper
Aramco Associated Co.
16875 JFK Boulevard
Houston TX 77032
Phone: 713-230-3718
Fax: 713-821-0336

Mr. Steve Horn
Phoenix Fire Inhibitor
North Road Industrial Estate
Ellesmere Port
Cheshire L6S 1AB
England
Phone: 44 151 356 4900
Fax: 44 151 356 1300

Ms. _April Horner
Conference Coordinator
FAA Technical Center
AAR-422/Bldg. 287
Atlantic City International Airport NJ 08405
Phone: 609-485-4471
Fax: 609-646-5229

Ms. Nancy Houston
America West Airlines
4000 E. Sky Harbor Blvd.
Phoenix AZ 85034
Phone: 602-693-3763
Fax: 602-693-3715

Mr. Lee Hoyt
Weber Aircraft
8943 Hazeltine Avenue
Panorama City CA 91402
Phone: 714-449-3000
Fax: 714-449-3046

Mr. Pierre Huggins
Airline Pilot's Association
PO Box 1169
535 Herdon Parkway
Herndon VA 22070-1169
Phone: 703-689-4211
Fax:

Mr. Frank Hughes
British Airways
PO Box 10, Heathrow Airport
Hounslow TW6 2JA
England
Phone: 44 181 862 3944
Fax: 44 181 562 2026

Mr. Paul Huston
Paul Huston & Assoc.
220 Snake Hill Road
Trussville AL 25173
Phone: 205-655-2961
Fax:

Dr. Michael Hynes
Hynes & Assoc.
100 Helicopter Drive
Frederick OK 73542
Phone: 405-335-5754
Fax: 405-335-5754

Mr. Zeinab Ibrahim
Saudia Airlines
PO Box 167, ci 959
Jeddah 21231
Saudi Arabia
Phone: 2 682 9700 X3094
Fax: 2 686 1988

Mr. Solafa Ibrahim
Saudia Airlines
PO Box 167, ci 959
Jeddah 21231
Saudi Arabia
Phone: 2 682 9700 X3094
Fax: 2 686 1988

Mr. Gilberto Imamura
Jamco America, Inc.
1018 80th Street, SW
Everett WA 98203
Phone: 206-347-4735
Fax: 206-355-0237

Mr. Doug Ingerson
FAA Technical Center
AAR-422/Building 287
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-4945
Fax: 609-646-5229

Mr. Xavier Janssens
CUPE Airline Div.
70 Park Street East #1403
Port Credit
Ontario L5G 1M5
Canada
Phone: 905-278-4187
Fax: 416-798-3411

Mr. Richard M. Johnson
FAA Technical Center
AAR-422/Building 203
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-6573
Fax: 609-646-5229

Ms. Kelli Jones
United Airlines
UAL-SFOFS
San Francisco International Airport
San Francisco CA 94128
Phone: 415-634-4649
Fax: 415-634-7211

Mr. Thomas Jurlina
Lermer Corporation
625 Industrial Way West
Eatontown NJ 07724
Phone: 908-544-0149
Fax: 908-389-8230

Mr. Konstantin Kallergis
DLR
Linder Hohe
D-51147 Cologne
Germany
Phone: 49 2203 6012168
Fax: 49 2203 64395

Mr. Hans Karl
Mankiewicz
Georg Wilhelm Strasse #189
Hamburg 21107
Germany
Phone: 49 40 751030
Fax: 49 40 75103418

Dr. Takao Kawakita
IREI Air Safety
12-13 Hata 1-chome
Ikeda-shi
Osaka-fu 563
Japan
Phone: 727 51 7078
Fax: 727 53 3922

Mr. Joseph C. Kilpatrick
Atlanta Aviation Int'l
6887 Barton Road
Morrow GA 30260
Phone: 404-961-5700
Fax: 404-961-9330

Ms. Brenda King
Canadian Reg. Airlines
3835 Corson Street
Suite 105
Torrance CA 90503
Phone: 310-540-2612
Fax: 310-540-0532

Mr. Yuri Kostev
IAC Aviation Register
Krjijanovsky Str. 7, Bldg. 1
GSP-7
Moscow 17875
Russia
Phone: 7095 129 57 77
Fax: 7095 125 51 95

Mr. Danko Kramar
FAA - ACO
10 Fifth Street
Third Floor
Valley Stream NY 11581-1200
Phone: 516-256-7509
Fax: 516-568-2716

Mr. Kent Kroener
De Havilland
123 Garratt Boulevard
Downsview Ontario M3K 1Y5
Canada
Phone: 416-375-4100
Fax: 416-375-4508

Ms. Linda Kunz
TWA
11495 Natural Bridge Road
Bridgeton CT 63044
Phone: 314-895-6889
Fax: 314-895-6679

Mr. Maurice Kuttler
FAA - ACO
3960 Paramount Blvd.
ANM-130L
Lakewood CA 90712
Phone: 310-627-5355
Fax:

Mr. David Lake
British Airways Plc
J205, Technical Block "A"
S403, Hatton Cross
London Heathrow Airport TW6 2JA
England
Phone: 44 181 562 5593
Fax: 44 181 562 8902

Mr. Wolfgang Lampa
Daimler-Benz Aerospace Airbus
Hunefeldstr. 1-5
Bremen 21899
Germany
Phone: 49 421 538 3484
Fax: 49 421 538 4180

Ms. Patrice LaSusa
Tapis Corporation
40 Radio Circle
Mt. Kisco NY 10549
Phone: 914-242-0012
Fax: 914-242-0021

Mr. Xuan Hui Le
Vietnam Airlines
Cialam Airport
Hanoi City
Vietnam
Phone: 84 4 272 011
Fax: 84 4 272 291

Mr. Jim Leach
FAA Technical Center
AAR-422/Building 287
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-4524
Fax: 609-646-5229

Mr. Michael Leclair
Flagship Airlines/Am. Eagle
PO Box 17228
Nashville TN 37218
Phone: 615-399-6415
Fax: 615-399-6384

Mrs. Betty Lecouturier
SNPNC
6, Rue Caroline
25017 Paris
France
Phone: 33 1 44 70 20 00
Fax: 33 1 44 70 20 10

Mr. Rene Letourneaw
Quebec Government
700 7th Rue
Sainte-Foy Quebec G2E 5W1
Canada
Phone: 418-877-8303
Fax: 418-877-6936

Ms. Dawn Leverett
American Airlines
4501 Highway 360
Ft. Worth TX 76155
Phone: 817-967-4133
Fax: 817-967-4063

Ms. Audrey Levine
Carnival Air Lines
Suite 205
1815 Griffin Road
Dania FL 33004-2213
Phone: 305-923-8672 Ext. 573
Fax: 305-921-5844

Mr. Claude Lewis
Transport Canada Aviation
Airworthiness Stardards
Tower 'C'/Place de Ville, 2nd Floor
Ottawa Ontario K1A 0N8
Canada
Phone: 613-990-5906
Fax: 613-996-9178

Dr. David Liddy
Ministry of Defence
Room 2180 Metropole Building
Northumberland Avenue
London WC2N 5BL
England
Phone: 44 171 218 4908
Fax: 44 171 218 4609

Mr. Jim Likes
Boeing Commercial Airplane Group
P.O. Box 3707
Mail Stop: OR-LA
Seattle, WA 98124-2207
Phone: 206-342-5600
Fax: 206-342-0914

Mr. Harrish Lilani
Nor-Fab Corporation
1032 Stanbridge Street
Norristown PA 19401
Phone: 610-270-0792
Fax: 610-277-6106

Mr. Bruce Lilley
De Havilland Inc.
Garratt Boulevard
Airworthiness Policy and Procedure
Downsview Ontario M3K 1Y5
Canada
Phone: 416-375-3781
Fax: 416-375-3781

Ms. Song-Shiang Lin
Ctr. for Aviation & Space Tech.
/Bldg. 11, 195
Chung Hsing Road, Section 4
Chutung Hsinchu 00710
Taiwan, Republic of China
Phone: 886 35 915950
Fax: 886 35 916 040

Mr. Lee Lipscomb
Southern Mills
PO Box 289
6501 Mall Blvd.
Union City GA 30291
Phone: 770-969-1000
Fax: 770-969-6846

Ms. Jiangbo Liu
CAAC
155 Dongsi Street West
Air Transport and Regulation Department
Beijing l00710
China
Phone: 86 10 4012305
Fax: 86 10 4013829

Mr. David Llewellyn
Macrsk Air Ltd.
22452249 Coventry Road
Birmingham B26 3NG
England
Phone: 44 121 743 9090
Fax: 44 121 743 4123

Ms. Gwyneth Lomahoza
Royal Swazi Nat'l Airways
PO Box 939
Matsapa Airport
Manzini
Swaziland
Phone: 92 68 861 46/7
Fax: 92 68 86148

Ms. Kathy Lord
Assoc. of Prof. Flight Attendants
1004 W. Euless Blvd.
Euless TX 76021
Phone: 817-540-0108
Fax: 817-540-2092

Dr. Richard Lyon
FAA Technical Center
AAR-423/Building 277
Fire Research Section
Atlantic City Iternational Airport NJ 08405
Phone: 609-485-6076
Fax: 609-485-5785

Mr. Pierre Maisonneuve
Transport Canada
330 Sparks Tower 'C'
Place de Ville
Ottawa Ontario K1A ON8
Canada
Phone: 613-998-4705
Fax: 613-990-1198

Mr. Jeffrey H. Marcus
FAA - CAMI
AAM-630
PO Box 25082
Oklahoma City OK 73125
Phone: 405-954-5555
Fax: 405-954-1010

Ms. Nora Marshall
NTSB
490 L'Enfant Plaza East, SW
Washington DC 20594
Phone: 202-382-6631
Fax: 202-382-6748

Mr. Jim Lonergan
Halotron, Inc.
3770 Howard Hughes Parkway
Suite 300
Las Vegas NV 89109
Phone: 703-735-2200
Fax: 703-735-4876

Mr. Virgil Lovett
IAM 2339 (Cont'l Airlines)
Hemisphere Center #303
Routes 1&9 South
Newark NJ 07114
Phone: 201-824-1400
Fax: 201-824-3025

Mr. Eric Magnusson
PetroStudies Co.
21370 Malmo
Sweden
Phone:
Fax: 11 46 40 221490

Ms. Laura Mamadopoulos
Bon Tour Travel
440 Rutherford Boulevard
Clifton NJ 07014
Phone: 201-773-1409
Fax: 201-890-9060

Mr. Tim Marker
FAA Technical Center
Building 275/AAR-422
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-6469
Fax: 609-485-5580

Ms. Shirley Martin
Evergreen Int'l Airlines
3850 Three Mile Lane
McMinnville OR 97128
Phone: 503-472-0011
Fax: 503-434-3443

Mr. Robert Massi
Air Line Pilots Assoc.
535 Herndon Parkway
Herndon VA 22070-1169
Phone: 703-689-4209
Fax: 703-689-4370

Mr. James Masten
3M Company
8744 Casa Grande Drive
Pittsburgh PA 15237
Phone: 412-367-7697
Fax: 412-367-7639

Mr. R.J. Mather
Transport Canada Aviation
Centennial Towers (AARDD)
200 Kent Street, 7th Floor
Ottawa Ontario K1A 0N8
Canada
Phone: 613-952-4320
Fax: 613-996-9178

Ms. Sylvie McDougall
Transport Canada
700 Leigh Capreol
Dorval Quebec H4Y 1G7
Canada
Phone: 514-633-3033
Fax: 514-633-3697

Dr. James McGrath
Virginia Polytechnic Institute
2111 Hahn Hall
Blacksburg VA 24061-0344
Phone: 703-231-5976
Fax: 703-231-8517

Mr. Robert McGuire
FAA Tech Ctr
AAR-431/Bldg. 201A
Aircraft Struct. Crashworthiness
Atlantic City Int'l Airport NJ 08405
Phone: 609-485-4494
Fax: 609-485-4004

Ms. Bonnie McKenna
Continental Micronesia
P.O. Box 8778
A.B. Won Pat International Airport
Tamuning GU 96931
Phone: 671-646-9586
Fax: 671-649-5220

Dr. G.A. "Mac" McLean
Federal Aviation Administration
AAM-630
PO Box 25082
Oklahoma City OK 73125
Phone: 405-954-5518
Fax: 405-954-1010

Mr. John Melo
Transport Canada Aviation
Transport Canada Bldg. (AARDD)
Tower 'C', 330 Sparks Street
Ottawa Ontario K1A 0NB
Canada
Phone: 613-952-4411
Fax: 613-996-9178

Mr. Salvatore Messina
Govmark Organization
Box 807
Bellmore NY 11710
Phone: 516-293-8944
Fax: 516-293-8956

Ms. Sharon Miles
FAA
2601 Meacham Blvd.
Ft. Worth TX 76137
Phone: 817-222-5122
Fax: 817-222-3961

Mr. Rocky Miller
Ind. Federation of Flight Attendants
720 Olive St/Suite 1700
St. Louis MO 63101
Phone: 314-621-1177
Fax: 314-895-6881

Mr. Nelson Miller
FAA Technical Center
Building 210/AAR-420
Aircraft Safety Directorate
Atlantic City International Airport NJ 08405
Phone: 609-485-4464
Fax: 609-485-4005

Mr. Joseph Mitchell
Wichita State Univ.
/1845 Fairmount
National Institute for Aviation Research
Wichita KS 67260-0093
Phone: 316-689-3478
Fax: 316-689-3175

Mr. Chris Moran
American Airlines
2141 Clayton Drive
Flower Mound TX 75028
Phone: 817-967-3954
Fax: 817-967-9352

Ms. Denise Morone
Carnival Air Lines
Suite 205
1815 Griffin Road
Dania FL 33004-2213
Phone: 305-923-8672 Ext. 730
Fax: 305-921-5844

Professor Helen Muir
Cranfield University
Department of Applied Psychology
Cranfield
Bedfordshire MK43 OAL
England
Phone: 44 1 234 750 111
Fax: 44 1 234 750 192

Mr. Nam Lien Nguyen
Vietnam Airlines
Cialam Airport
Hanoi City
Vietnam
Phone: 84 4 272 011
Fax: 84 4 272 291

Mr. Rafael Miranda
Continental Airlines
15333 JFK Boulevard
Suite 425
Houston TX 77032
Phone: 713-985-1454
Fax: 713-985-2780

Mr. Giovanni Modugno
AvioInteriors
Via Appia KM 66.400
Torte Ponte
04013 Latina
Italy
Phone: 39773 689 296
Fax: 39 773 63 1546

Ms. Johanne Morin
S.C.F.P. AirTransat
59 Rue St. Jacques Ouest
Bureau 400
Montreal Quebec H2Y 1K9
Canada
Phone: 514-281-8439
Fax: 514-281-0821

Mr. Peter Morris
Delta Airlines
1775 Aviation Boulevard
Atlanta GA 30320
Phone: 404-714-3150
Fax: 404-714-3304

Mr. Mark Muller
Galaxy Scientific Corp.
2500 English Creek Avenue
Building 11
Pleasantville NJ 08232
Phone: 609-645-0900
Fax: 609-645-2881

Dr. Vernon Nicolette
Sandia National Labs
Organization 1513, MS 0835
PO Box 5800
Albuquerque NM 87185
Phone: 505-844-6004
Fax: 505-844-8251

Mr. Roy Nishizaki
Transportation Development Ctr.
/Transport Canada
800 Rene Levesque Blvd. W/6th Fl.
Montreal H3B 1X9
Canada
Phone: 514-283-0026
Fax: 514-283-7158

Mr. Richard Norsworthy
British Airways
Compass Centre (5709)
Heathrow Airport
Hounslow TW6 2JA
England
Phone: 44 181 513 0031
Fax: 44 181 513 0069

Mr. John O'Donnell
Air Cruisers Co.
PO Box 180
Highway 34 South & Allaire Airport
Belmar NJ 07719
Phone: 908-681-3527
Fax: 908-280-8212

Mr. Michael Oleson
Aircraft Modular Products
4000 Northwest 36th Avenue
Miami FL 33142
Phone: 305-633-6817
Fax: 305-635-8409

Mr. Bill Ottignon
Kiwi Int'l Airlines
Hemisphere Center
U.S. 1&9 South
Newark NJ 07114
Phone: 305-874-6727
Fax: 201-645-1161

Mr. Rick Panchuk
Transport Canada
Macdonald-Cartier Airport
58 Service Road
Gloucester Ontario
Canada
Phone: 613-990-9305
Fax: 613-989-7020

Mr. Themba Nkenene
South African Airways
/Flight Operations Trng. Ctr.
Room 203
Johannesburg International Airport
Africa
Phone: 27 11 978 6439
Fax: 27 11 978 6814

Mr. Michael O'Donnell
Imi-Tech
307 S. First Street
Suite C
Mt. Vernon WA 98273
Phone: 360-336-5182
Fax: 360-336-5054

Mr. John Oberst
Lifetech, Inc.
11350 Random Hills Road
Suite 800
Fairfax VA 22030
Phone: 703-273-2009
Fax: 703-591-3049/273-9516

Mr. Dale Onderak
Schneller, Inc.
6019 Powdermill Road
PO Box 670
Kent OH 44240
Phone: 216-673-1400
Fax: 216-673-7327

Mr. Jean-Luc Paillet
SNPNC
6, Rue Caroline
25017 Paris
France
Phone: 33 1 44 70 20 00
Fax: 33 1 44 70 20 10

Ms Monica L. Pastor
ACEO Airlines
Aeropuerto Enrique Claya Herrera
OF 216 Medellin
Colombia
Phone: 2 85 8411
Fax: 255 78 20

Mr. A.T. Peacock

1625 Edgemoor Lane
Everett WA 98203
Phone: 206-348-5919
Fax:

Mr. Michael Peat
United Airlines
Int'l Assoc. of Machinists
717 Ridge Circle
Streamwood IL 60107
Phone: 312-601-3547
Fax: 312-601-3752

Mr. Knut Pederson
Cessna Aircraft Co.
Department 009C
Three Cessna Blvd.
Wichita KS 67215-1400
Phone: 316-941-8704
Fax: 316-941-7925

Mr. Neil Percival
Percival Associates
The Sidings
Knowls, Fareham
Hants PO17 5LZ
England
Phone: 44 1329 853 814
Fax: 44 1329 854 013

Mr. Lou Perdoni
Air Cruisers Co.
PO Box 180
Belmar NJ 07719-0180
Phone: 908-681-3527
Fax: 908-681-9163

Mr. Gaetan Perron
Canadian Forces Fire Marshal-2
National Defence Headquarters
Nat'l Denfece Hdqtrs/101 Col. By Dr.
Ottawa Ontario K1A OK2
Canada
Phone: 613-945-7870
Fax: 613-996-1753

Dr. James Peterson
Boeing Commercial Airplane Group
PO Box 3707
MS: 73-48
Seattle WA 98124-2207
Phone: 206-237-8243
Fax: 206-237-0052

Ms. Margie Peterson
Assoc.of Flight Attendants
American Eagle
6400 Shafer Court-Suite 740
Rosemont IL 60018-4930
Phone: 708-696-4310
Fax: 708-292-7180

Mr. Jean-Francois Petit
CEAT
23, avenue Henri Guillaumet
31056 Toulouse Cedex
France
Phone: 33 61 58 74 10
Fax: 33 61 58 74 78

Mr. John Petrakis
FAA
800 Independence Avenue, SW
Washington DC 20591
Phone: 202-267-9274
Fax: 202-267-5340

Mr. Robert Plante
Transport Canada
Macdonald-Cartier Airport
58 Service Road
Gloucester Ontario
Canada
Phone: 613-998-9223
Fax: 613-991-0365

Mr. Ekwin Poeze
TNO Crash-Safety Research Ctr.
PO Box 6033
2600 JA Deift
The Netherlands
Phone: 31 15 2696951
Fax: 31 152624321

Mr. Nick Povey
U.K.Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone: 44 1 293 573 347
Fax: 44 1 293 573 981

Mr. Larry Price
Air New Zealand
c/o Flight Operations International
Private Bag 92007
Auckland
New Zealand
Phone: 649 256 3547
Fax: 649 256 3574

Mr. Fuguang Qin
Aviation Industries of China
Dept. of Commercial Aircraft
No. 67 Jiao Nan Street
Beijing 00712
People's Republic of China
Phone: 86 10 4013322 Ext. 2354
Fax: 86 10 403 2615

Mr. Jerry Ramos
Lermer Corporation
625 Industrial Way West
Eatontown NJ 07724
Phone: 908-544-8611
Fax: 908-389-8230

Mr. Duane Randall
Akro Fireguard Products
9001 Rosehill Road
Lenexa KS 66215
Phone: 913-888-7172
Fax: 913-888-7372

Mr. Fernando Ranieri
Embraer-Empresa Brasil.
Ave. Brig. Faria Lima 2170
(DTE/TEE/EIN)/Dep. 12227-901
Sao Jose Dos Campos-SF
Brasil
Phone: 55 123 251230
Fax: 55 12 411 675

Miss Sarah-Jane Prew
Civil Aviation Trng. Mag.
/Halldale Publishing
84 Alexandra Rd./Farnborough
Hampshire GU14 6DD
England
Phone: 44 1252 517974
Fax: 44 1252 512714

Ms. Judith Procter
USAir Shuttle
13 Madison Avenue
Bayville NY 11709
Phone: 516-628-9226
Fax: 516-628-3657

Dr. Shahid Qureshi
Georgia Pacific Resins, Inc.
2883 Miller Road
Decatur GA 30035-4088
Phone: 404-593-6849
Fax: 404-593-6801

Mr. Jean-Marc Rampin
Aerospatiale
316, route de Bayonne
31060 Toulouse Cedex 03
France
Phone: 33 69 93 97 88
Fax: 33 69 93 69 5 5

Mr. N. Rangarajan
GESAC
Route 2
PO Box 339A
Kearneysville WV 25430
Phone: 304-267-6704
Fax: 304-267-6821

Mr Kevin Reifschneider
Learjet Inc.
PO Box 7707
One Learjet Way
Wichita KS 67277-7707
Phone: 316-946-3211
Fax: 316-946-2990

Ms. Christine Reiter
Lufthansa German Airlines
Lufthansa-Rasis
FRA OK 32
60546 Frankfurt
Germany
Phone: 49 69 696 7022
Fax: 49 69 696 3274

Dr. Alex Richman
Algo Plus Consulting
5959 Spring Gardon Road #609
Halifax Nova Scotia R3H 1YS
Canada
Phone: 902-420-1035
Fax:

Mr. Jacques Robillard
Mankiewicz
40 Rue Des Binelles
92310 Sevres
France
Phone: 33 1 45 07 16 66
Fax: 33 1 45 34 06 29

Mr. Henry Roux
Roux International
PO Box 1513
Lancaster PA 17608
Phone: 717-464-5421
Fax:

Ms. Ronda Ruderman
Assoc.of Flight Attendants
1217 SW 170 Street
Seattle WA 98166
Phone: 206-244-3619
Fax: 206-244-3619

Mr. Anthony Saracino
DuPont
Chestnut Run Plaza
PO Box 80702
Wilmington DE 19880-0702
Phone: 302-999-4094
Fax: 302-999-2395

Mr. Rick Reynolds
USAir, Inc.
PO Box 12346(Hangar 3, Room 346)
Pittsburgh International Airport
Pittsburgh PA 15231
Phone: 412-472-7064
Fax: 412-472-4190

Mr. David Roberts
Calspan SRL Corp.
4455 Genesee Street
PO Box 400
Buffalo NY 14225
Phone: 716-631-6816
Fax: 716-631-6845

Ms. Deborah Roland
Assoc.of Prof. Flight Attendants
1004 W. Euless Boulevard
Euless TX 76021
Phone: 703-754-7743
Fax: 817-540-2077

Ms. Joanne Royal
America West Airlines
4000 E. Sky Harbor
Phoenix AZ 85034
Phone: 602-693-8442
Fax: 602-693-8448

Mr. M. Sadeghi
Cranfield Impact Centre
Wharley End
Cranfield
Bedford MK43 OJR
England
Phone: 44 1234 751361
Fax: 44 1234 750944

Mr. Constantine Sarkos
FAA Technical Center
Building 201/AAR-422
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-5620
Fax: 609-485-4004

Mr. Wolfgang Lampa
Daimler-Benz Aerospace Airbus
Hunefeldstr. 1-5
Bremen 21899
Germany
Phone: 49 421 538 3484
Fax: 49 421 538 4180

Mr. Jim Likes
Boeing Commercial Airplane Group
PO Box 3707
MS: OR-MM
Seattle WA 98124
Phone:
Fax: 206-717-0460

Mr. Jeffrey H. Marcus
FAA - CAMI
AAM-630
PO Box 25082
Oklahoma City OK 73125
Phone: 405-954-5555
Fax: 405-954-1010

Mr. Tim Marker
FAA Technical Center
Building 275/AAR-422
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-6469
Fax: 609-485-5580

Dr. G.A. "Mac" McLean
Federal Aviation Administration
AAM-630
PO Box 25082
Oklahoma City OK 73125
Phone: 405-954-5518
Fax: 405-954-1010

Professor Helen Muir
Cranfield University
Department of Applied Psychology
Cranfield
Bedfordshire MK43 OAL
England
Phone: 44 1 234 750 111
Fax: 44 1 234 750 192

Dr. James Peterson
Boeing Commercial Airplane Group
PO Box 3707
MS: 73-48
Seattle WA 98124-2207
Phone: 206-237-8243
Fax: 206-237-0052

Mr. Nick Povey
U.K.Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone: 44 1 293 573 347
Fax: 44 1 293 573 981

Mr. M. Sadeghi
Cranfield Impact Centre
Wharley End
Cranfield
Bedford MK43 OJR
England
Phone: 44 1234 751361
Fax: 44 1234 750944

Mr. Constantine Sarkos
FAA Technical Center
Building 201/AAR-422
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-5620
Fax: 609-485-4004

Mr. Romi Singh
Aviation Research Corporation
515 Chemin de l'Anse
Vaudreuil (Montreal) Quebec J7V 8P3
Canada
Phone: 514-455-6699
Fax: 514-455-2242

Dr. Richard Smith

7040 Wick Lane
Rockville MD 20855-1963
Phone:
Fax:

Mr. Phillip Sarozek
S. California Safety Inst.
3838 Carson Street
Suite 105
Torrance CA 90503
Phone: 310-540-2616
Fax: 310-540-0532

Mr. George Schneider
Sikorsky Aircraft
6900 Main Street
M/S: 5300A
Stratford CT 06497
Phone: 203-286-4785
Fax: 203-286-7850

Mr. John Schuster
3M
Bldg. 223-65-04
PO Box 33223
St. Paul MN 55144
Phone: 612-736-6055
Fax: 612-736-8643

Mr. Ricaud Sebastion
DCAe
26 boulevard Victor
00460 Arimces
Paris
France
Phone: 33 1 455 25183
Fax: 33 1 45 52 61 76

Mr. Gunther Selzer
Lufttransport-Unternehmen
Flughafen, Halle 8
40474 Dusseldorf
Germany
Phone: 49 211 9418 705
Fax: 49 211 9418 713

Ms. Heather Sheats
USAir
AFA Loral Council 89
4827 Park Road Suite 105
Charlotte NC 28209
Phone: 704-527-0325
Fax: 704-527-5040

Mr. Chin Chia Shiau
China Airlines
No. 3, Alley 123
Lane 405, Tunc Hwa N. Road
Taipei Taiwan
People's Republic of China
Phone: 886 2 712 3141 6604
Fax: 886 2 514 6304

Mr. W.H. Shook
Douglas Aircraft Company
3855 Lakewood Blvd.
Mail Code: 802-27
Long Beach CA 90801-0200
Phone: 310-593-8852
Fax: 310-982-0775

Mr. Jamil Sindi
Saudia Airlines
PO Box 167, ci 959
Jeddah 21231
Saudi Arabia
Phone: 2 682 9700 X3094
Fax: 2 686 1988

Mr. Romi Singh
Aviation Research Corporation
515 Chemin de l'Anse
Vaudreuil (Montreal) Quebec J7V 8P3
Canada
Phone: 514-455-6699
Fax: 514-455-2242

Mr.; Ed Smialowicz
Air Cruisers Co.
PO Box 180
Highway 34 South & Allaire Airport
Belmar NJ 07719
Phone: 908-681-3527
Fax: 908-280-8212

Mr. Sherman Smith
Orcon Corporation
1570 Atlantic Street
Union City CA 94587-3299
Phone: 510-489-8100
Fax: 510-471-3410

Dr. Novis Smith
RK Carbon Fibers
433 Bainbridge Street
Philadelphia PA 19147
Phone: 215-627-3200
Fax: 215-922-1211

Dr. Richard Smith

7040 Wick Lane
Rockville MD 20855-1963
Phone:
Fax:

Mr. Mike Solomon
British Airways
J205/Heathrow Airport
Hatton Cross, LIIR
Heathrow TBA, S403
England
Phone: 44 181 562 1139
Fax: 44 181 562 8902

Ms. Louise Speitel
FAA Technical Center
AAR-422/Building 277
Fire Safety Section
Altnatic City International Airport NJ 08405
Phone: 609-485-4528
Fax: 609-646-5229

Mr. Tony Spuria
Advanced Foam Products
200 Executive Way
Ponte Verda FL 32082
Phone: 904-285-1250
Fax: 904-285-1002

Mr. Bob Stacho
FAA - ACO
Los Angeles ACO
3690 Paramount Boulevard
Lakewood CA 90712
Phone: 310-627-5334
Fax: 310-627-5210

Dr. Eugene Steadman
Hoechst Celanese Corp.
919 18th Street, NW
Suite 700
Washington DC 20006
Phone: 202-276-2890
Fax: 202-296-7268

Mr. Goran Steen
Gullers Corporation
Box 7004
10386 Stockholm
Sweden
Phone: 46 8 611 0750
Fax: 46 8 611 0780

Mr. Robert Stolpe
ACR Electronics
5757 Ravenswood Road
Ft. Lauderdale FL 33312
Phone: 305-981-3333
Fax: 305-926-2385

Mr. Vidar Storsletten
SAS
Production Standards & Development
Production Division - Stogs
S-195 87 Stockholm
Sweden
Phone: 46 8 797 1811
Fax: 46 8 797 2930

Mr. Charles Story
Magee Plastics Co.
303 Bursh Creek Road
Warrendale PA 15086
Phone: 412-776-2220
Fax: 412-776-7696

Mr. Felix Stossel
Swissair
Ch8058
Zurich-Teps
Switzerland
Phone: 41 1 812 0930
Fax: 41 1 812 9098

Ms. Joan Strow
Paula Wingate
TWA Corporate Safety Department
11495 Natural Bridge Road
St. Louis MO 63044
Phone: 314-895-5588
Fax: 314-895-6679

Mr. Sadaaki Suzuki
JAMCO Corporation
1-100 Takamatsu-cho
Tachikawa
Tokyo 00190
Japan
Phone: 81 425 28 1608
Fax: 81 425 27 8097

Ms. Harriet Taukave
Air Pacific Ltd.
PO Box 9266
Nadi Airport
Nadi
Fiji
Phone: (679) 720 777 Ext. 206
Fax: (679) 723 400

Mr. Philip Thatch
Atlanta Aviation Int'l
6887 Barton Road
Morrow GA 30260
Phone: 404-961-5700
Fax: 404-961-9330

Ms. Heli Thilman
Finnair
Mail Code: OFH/62
01053 Finnair
Finland
Phone: 358 0 818 5253
Fax: 358 0 818 6700

Ms. Joellen Thompson
Douglas Aircraft Co.
PO Box 1771
Long Beach CA 90801-1771
Phone: 310-497-6644
Fax: 310-593-8302

Mr. David Supplee
USAir/IAM
12410 Regency Avenue
Seminole FL 34642
Phone: 813-397-6697
Fax: 813-391-3523

Mr. Robert Swain
Air Line Pilots Assoc.
535 Herndon Parkway
Herndon VA 22070-1169
Phone: 703-689-4209
Fax: 703-689-4370

Ms. Nanette Terbush
Am. Eagle/Wings West
835 Airport Drive
San Luis Obispo CA 93403-8115
Phone: 805-541-1010 Ext. 128
Fax: 805-542-0698

Mr. Jacky Therond
Sogerma-Socea
Ancien Arsenal-BP 109
17303 Rochefort Cedex
France
Phone: 33 4683 62 63
Fax: 33 46 83 63 45

Mr. Gary Thompson
Delta Air Lines
Hartsfield-Atlanta International Airport
Atlanta GA 30320
Phone: 404-715-1657
Fax: 405-715-1680

Mr. Tom Tompkins
3M Company
3M Center
Building 207-15-23
St. Paul MN 55144
Phone: 612-736-3250
Fax: 612-733-0221

Mr. Tom Tracy
Clarion Technologies
Box 4042
Boise ID 83704
Phone: 208-322-1228
Fax: 208-323-7660

Ms. Helene Tremblay
Air Inuit
230 2nd Avenue
Aeroport International Jean-Lesage
Quebec G2E 5W1
Canada
Phone: 418-872-0015
Fax: 418-872-6822

Mr. Jed Tyson
Cessna Aircraft Co.
Department 009C
Three Cessna Blvd.
Wichita KS 67215-1400
Phone: 316-941-7032
Fax: 316-941-7925

Mr. Richard Vandame
SAE
400 Commonwealth Drive
Warrendale PA 15096-0001
Phone: 412-776-4841
Fax: 412-776-0243

Mr. Antony Vaudrey
British Embassy
3100 Massachusetts Avenue NW
Washington DC 20008
Phone: 202-463-7529
Fax: 202-223-9368

Ms. Sandra Vega
American Eagle/Simmons
O'Hare International Airport
PO Box 66374
Chicago IL 60666
Phone: 312-686-2600
Fax: 312-686-3294

Mr. Lionel Virr
U.K.Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone: 44 1 293 573 129
Fax: 44 1 293 573 975

Mr. Hong Nhat Vo
Vietnam Airlines
Cialam Airport
Hanoi City
Vietnam
Phone: 84 4 272 011
Fax: 84 4 272 291

Mr. Michael Von Reth
Flight Attend. Assoc.-Australia
4th Floor
388 Sussex Street
Sydney NSW 02000
Australia
Phone: 2 201 3800
Fax: 2 201 3810

Dr. Tong Vu
FAA Tech Ctr.
AAR-431/Bldg. 214
Aircraft Struct. Crashworthiness
Atlantic City International Airport NJ 08405
Phone: 609-485-4774
Fax: 609-485-4004

Ms. Andrea Waas
Wings of Light
16845 N. 29th Avenue
Suite 1-448
Phoenix AZ 85023
Phone: 602-516-1115
Fax: 602-863-2805

Ms. Wendy Wade
Trans World Airlines
11495 Natural Bridge Road
Bridgeton MO 63044
Phone: 314-895-6663
Fax:

Ms. Melanie Wahmund
American Airlines
P.O. Box 619617
MD 889 GSWFA
Dallas/Ft. Worth Airport TX 75261-9617
Phone: 817-967-4189
Fax: 817-967-5965

Ms. Melanie Wahrmund
American Airlines
4501 Highway 360
Ft. Worth TX 76155
Phone: 817-967-4133
Fax: 817-967-4063

Mr. Robert Walker
Skyline Products/Division Isovolta
PO Box 287
495 Territorial Road
Harrisburg OR 97446
Phone: 503-995-6395
Fax: 503-995-8425

Professor W. Angus Wallace
Queen's Medical Centre
University Hospital
Nottingham NG7 2UH
England
Phone: 44 115 970 9407
Fax: 44 115 942 3656

Mr. John Walma
Fell-Fab Products
2343 Barton Street East
Hamilton, Ontario L8E 5V8
Canada
Phone: 905-560-9230
Fax: 905-560-9846

Mr. Shu Wang
China Airlines
No. 3, Alley 123
Lane 405, Tunc Hwa N. Road
Taipei Taiwan
People's Republic of China
Phone: 886 2 712 3141 EXT. 6604
Fax: 886 2 514 6304

Ms. Joan Webb
USAir
Hangar 3/PIT/0345
Pittsburgh International Airport
Pittsburgh PA 15231
Phone: 412-472-4701
Fax: 412-472-4190

Mr. Ingo Weichert
Daimler-Benz Airbus
Daimler-Benz Aerospace Airbus
Kreetslag 10
D-21111 Hamburg
Germany
Phone: 49 40 7437 5624
Fax: 49 40 7437 6090

Mr. Klas Wejle
SAS -Scandinavian Airlines Sys.
Dept. OSLTK
N-1330 Oslo Fornebu Airport
Norway
Phone: 47 67 59 84 92
Fax: 47 67 59 60 01

Mr. Ronald Welding
Air Transport Association of America
/Suite 1100
1301 Pennsylvania Ave, NW
Washington DC 20004-1707
Phone: 202-626-4012
Fax: 202-626-4149

Mr. Eskil Wiklund
LFV-Swedish CAA
Flight Safety Department
S-60179 Norrkoping
Sweden
Phone: 46 11 192 074
Fax: 46 11 1925 75

Ms. Pat Williams-Harter
Assoc. of Flight Attendants
1302 East Mesquite
Gilbert AZ 85296
Phone: 800-603-3369
Fax:

Mr. Chris Witkowski
Assoc. of Flight Attendants
1625 Massachusetts Avenue NW
3rd Floor
Washington DC 20036
Phone: 202-328-5400
Fax:

Mr. Brian Wozniak
IAM 2339/Cont'l Airlines
Hemisphere Center #303
Routes 1&9 South
Newark NJ 07114
Phone: 201-824-1400
Fax: 201-824-3025

Mr. Gary Wright
Atlas Electric Devices
4114 N. Ravenswood Avenue
Chicago IL 60613
Phone: 312-327-4520
Fax: 312-327-4023

Captain Ray Yeates
Aer Lingus
Dublin Airport
Dublin
Ireland
Phone: 353 1 7052656
Fax: 353 1 745 6460

Ms. Helen Zienkievicz
United Airlines
P.O. Box 66110
Inflight Safety - WHQSY
Chicago IL 60666
Phone: 708-952-4438
Fax: 708-952-7269

Frances Wokes
Transport Canada (AARXF)
Place De Ville
Tower 'C', 4th Fl/330 Sparks St.
Ottawa Ontario K1A ON8
Canada
Phone: 613-991-3988
Fax: 613-956-1602

Mr. Nigel Wright
AVRO Int'l Aerospace
Chester Road/Post Stn. No. 34
Woodford
Stockport 9K7 1QR
England
Phone: 44 161 955 4158
Fax: 44 161 955 3028

Mr. Fred Wright
Transport Canada
1100, 9700 Jasper Avenue
Edmonton Alberta T5J 4E6
Canada
Phone: 403-495-3856
Fax: 403-495-6659

Ms. Bixiu Zhang
CAAC
155 Dongsi Street West
Air Transport and Regulation Department
Beijing I00710
China
Phone: 86 10 401 3829
Fax: 86 10 401 3829

Mr. Richard Zimmermann
Simula Gov't Prod.
10016 S. 51st Street
Phoenix AZ 85044
Phone: 602-730-4427
Fax: 602-893-8643

KEYNOTE SPEAKERS

Mr. Vittorio Fiorini
RAI
Via del Tritone 169
Roma 00187
Italy
Phone: 39 6 678 3696
Fax: 39 6 678 1318

Mr. R.J. Mather
Transport Canada Aviation
Centennial Towers (AARDD)
200 Kent Street, 7th Floor
Ottawa Ontario K1A 0N8
Canada
Phone: 613-952-4320
Fax: 613-996-9178

Mr. Nelson Miller
FAA Technical Center
Building 210/AAR-420
Aircraft Safety Directorate
Atlantic City International Airport NJ 08405
Phone: 609-485-4464
Fax: 609-485-4005

Mr. Lionel Virr
U.K.Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone: 44 1 293 573 129
Fax: 44 1 293 573 975

SESSION CHAIRMEN

Mr. Cliff Barrow
U.K.Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone:
Fax: 44 1 293 573 975

Mr. Nick Butcher
U.K.Civil Aviation Authority
Safety Regulation Group
Aviation House
Gatwick RH6 OYR
England
Phone:
Fax: 44 1 293 573 991

Mr. Jean-Paul Deneuville
STPA/N Airworthiness Dept.
4 Avenue de la Porte d'Issy
75015 Paris
France
Phone:
Fax: 33 1 4552 4301

Mr. Jeff Gardlin
FAA Aircraft Cert. Div.
1601 Lind Avenue, SW
ANM-114
Renton WA 98055-4056
Phone: 206-227-2136
Fax: 206-227-1100

Mr. Claude Lewis
Transport Canada Aviation
Airworthiness Stardards
Tower 'C'/Place de Ville, 2nd Floor
Ottawa Ontario K1A 0N8
Canada
Phone: 613-990-5906
Fax: 613-996-9178

Ms. Nora Marshall
NTSB
490 L'Enfant Plaza East, SW
Washington DC 20594
Phone: 202-382-6631
Fax: 202-382-6748

Mr. Constantine Sarkos
FAA Technical Center
Building 201/AAR-422
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-5620
Fax: 609-485-4004

PRESENTERS

Mr. Thomas Barth
Simula, Inc.
10016 South 51st Street
Phoenix AZ 85044-5299
Phone: 602-730-4185
Fax: 602-893-8643

Mr. Ray Cherry
R.G.W. Cherry & Assoc.
75, Moorlands
Welwyn Garden City
Herts AL7 4QJ
England
Phone: 44 1707373767
Fax: 44 1707 392129

Mr. Kirke Comstock
United Airlines
San Francisco Int'l Airport - SFO EG
Maint. Operations Center
San Francisco CA 94128
Phone: 415-634-7015
Fax: 415-634-7070

Mr. Stephane Deharvengt
DGAC & SPACT/R
48 Rue Desmoulins
Issy Les Moulineaux 92452
France
Phone: 33 1 41 09 46 87
Fax: 33 1 41 09 45 13

Mr. Charles A. DeJohn
Federal Aviation Administration
AAM-610
PO Box 25082
Oklahoma City OK 73125
Phone: 405-954-5519
Fax: 405-954-1010

Mr. Darren Dodd
Faverdale Engineering Group
Faverdale Industrial Estate
Darlington Co. Durham DL3 0QL
England
Phone: 44 1 325 381220
Fax: 44 1 325 381218

Mr. Ronald Downs
British Airways
Compass Centre (5709)
Heathrow Airport
Hounslow TW6 2JA
England
Phone: 44 181 513 0030
Fax: 44 181 513 0069

Dr. Thor Eklund
FAA Technical Center
Building 204/AAR-423
Fire Research Section
Atlantic City International Airport NJ 08405
Phone: 609-485-5532
Fax: 609-485-5785

Dr. Mario Farioli
Ctr of Italian Aerospace Res.
Via Maiocise
81043 Capua
Italy
Phone: 39 823 623 110
Fax: 39 823 623 126

Mr. Larry Fitzgerald
FAA Technical Center
Building 287/AAR-422
Fire Safety Section
Atlantic City International Airport NJ 08405
Phone: 609-485-5852
Fax: 609-646-5229

Mr. Gary Frings
FAA Technical Center
AAR-431/Building 201A
Aircraft Structural Crashworthiness
Atlantic City International Airport NJ 08405
Phone: 609-485-5781
Fax: 609-485-4004

Mr. Ed Galea
University of Greenwich
Woolwich Campus
Numerical Modelling Ctr/Wellington St
Woolwich London SE18 6PF
England
Phone: 44 181 331 8730
Fax: 44 181 331 8665

Professor W. Angus Wallace
Queen's Medical Centre
University Hospital
Nottingham NG7 2UH
England
Phone: 44 115 970 9407
Fax: 44 115 942 3656

CONFERENCE ORGANIZATION

Mr. Cliff Barrow
U.K. Civil Aviation Authority
Safety Regulation Group
Gatwick, England

Mr. Jean-Paul Deneuville
STPA/N
Airworthiness Department
Paris, France

Mr. Jeff Gardlin
Federal Aviation Administration (FAA)
Aircraft Certification Service
Renton, Washington

Mr. Graham Greene
U.K. Civil Aviation Authority
Safety Regulation Group
Gatwick, England

Mr. Richard Hill
Federal Aviation Administration
(FAA) Technical Center
Atlantic City Int'l Airport, New Jersey

Ms. April Horner
Galaxy Scientific Corporation
Conference Coordinator
Egg Harbor Township, New Jersey

Mr. Claude Lewis
Transport Canada Aviation
Airworthiness Standards
Ottawa, Ontario, Canada

Mr. Jeffrey H. Marcus
Federal Aviation Administration (FAA)
Civil Aeromedical Institute (CAMI)
Oklahoma City, Oklahoma

SESSION CHAIRMEN

Evacuation Session
Mr. Jean-Paul Deneuville
STPA/N
Airworthiness Department

Mr. Claude Lewis
Transport Canada Aviation
Airworthiness Standards

Inflight Emergencies Session
Mr. Nick Butcher
U.K. Civil Aviation Authority
Safety Regulation Group

Ms. Nora Marshall
National Transportation Safety Board
(NTSB)

Crash Dynamics Session
Mr. Cliff Barrow
U.K. Civil Aviation Authority
Safety Regulation Group

Fire Safety Session
Mr. Jeff Gardlin
Federal Aviation Administration
Aircraft Certification Service

KEYNOTE SPEAKERS

Mr. Vittorio Fiorini
JAA
Research Committee

Mr. Robert J. Mather
Transport Canada Aviation
Airworthiness

Mr. Nelson Miller
Federal Aviation Administration
(FAA) Technical Center

Mr. Lionel Virr
JAA
Cabin Safety Study Group

*U.S. GOVERNMENT PRINTING OFFICE:1996-705-751